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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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XXXV.

ON THE DISTRIBUTION OF ACTIVITY IN RADIUM THERAPY UNDER DIFFERENT CONDITIONS OF SCREENING.

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[Read January 24. Published April 13, 1922.]

Introduction.

A great deal of work has been done by various experimenters on the passage of α, β, and γ rays from radioactive substances through various kinds of matter, and on the secondary radiations set up.[1] Some of the results so obtained are rather inaccessible to medical workers in this country, and, moreover, their application to specific problems is generally rendered difficult by the complexity of the radiations, and by the necessity of combining the effect of absorption with the geometrical effect of distance.

An attempt has accordingly been made to reduce the user's problem to its simplest form by carrying out tests on the screening effects of various materials for the combined β and γ radiation emitted by an emanation tube at a fixed distance, and combining the results so obtained with the geometrical law of distance, so as to calculate the variation of activity with distance from the source in some typical cases.[2]

It seems probable that we may take the ionisation produced in the tissues as a measure of the physiological action. This ionisation may be due to:—(1) α rays, (2) primary β rays, (3) secondary β rays produced by

[1] For a review of recent work on the absorption of γ rays see "Radium," October, 1921.

[2] The validity of this method has been questioned by Kroenig and Freidrich ["Strahlentherapie," xi, p. 20, 1920]. Their direct measurements of γ radiation at a depth of 10 cms. in water gave results about twice as great as they obtained by calculation. They attributed the discrepancy to scattered radiation. On the other hand, Sievert ["Acta Radiologica," i, p. 89, 1921] obtained results at smaller depths according excellently with theory. It would seem unlikely that, under the conditions prevalent in radium therapy, scattered radiation could cause a large error for distances up to 10 cms.

the action of the γ rays on any screen used, and (4) secondary β rays produced in the tissues by the passage of the γ rays.

The α rays are completely stopped by less than 0·1 mm. of flesh, or about 0·03 mm. of glass. This being much less than the usual thickness of wall of an emanation tube, they produce no effect with the common modes of treatment. If, however, emanation solution be injected, the effect of the α rays must far outweigh that of the others in all regions to which the solution finds access, as their relatively large energy and great absorbability cause, within their range, an intensity of ionisation about 100 times that due to the β rays.

The primary β rays, as may be inferred from the curves shown in fig. 2, are completely absorbed by about 1·5 cms. of flesh, or 1·5 mm. of brass. Owing to this comparatively rapid absorption, they produce relatively intense ionisation, that due to unscreened β rays being about 100 times that due indirectly to the γ rays from the same source.

Secondary β rays, produced by the passage of γ rays through ordinary matter, are similar in ionising properties to the primary β rays emitted by the radioactive source. They are, however, considerably less penetrating than the hardest of the primary β rays. The velocity, and hence the penetrating power of secondary β rays, increases with the hardness of the γ radiation to which they are due, so that the secondary β rays produced by γ rays are much more penetrating than those due to X rays.

If a metal screen is interposed between the source and the flesh, the surface of the latter is exposed to the secondary β radiation from the screen, but is deficient in secondary radiation from the flesh as compared with a point deeper down.

The effect at a point in the tissue, then, varies with depth owing to the combined effect of the following causes:—

(1) Absorption of primary β rays in the screen and the tissue.

(2) Absorption of secondary β rays due to the screen.

(3) Initial increase with depth of the secondary β rays due to the tissue.

(4) Absorption of γ rays, and consequent reduction of secondary β rays.

(5) Geometrical effect of distance.

The joint result of effects (1) to (4) has been estimated by experiments with an electroscope at a fixed distance from the source, and approximate calculations then made to include the effect of distance in some typical cases.

Apparatus.

The electroscope used is shown in section in fig. 1, which also shows the emanation tube mounted on a wooden block at a fixed distance below

the electroscope. It is made of brass, with a lead base 4 mm. thick, in the centre of which is a circular window, 2·7 cms. in diameter, covered with a sheet of gelatine, 0·02 mm. thick, off an unexposed but "fixed" photographic plate. The electroscope is lined with leather about 2·5 mm. thick, impregnated with gelatine containing a little mercuric chloride to increase its electrical conductivity. This lining ensures that the secondary radiation from the walls of the electroscope resembles as nearly as possible that in animal tissue, so that the rate of motion of the gold leaf is a fair measure of the total ionisation that would occur in the tissue under the same conditions of radiation. The electroscope was always charged to about 250 volts by means of a Tucker hygroscopic battery before each test. The approximate constancy of the initial voltage rendered the motion of the leaf more regular.

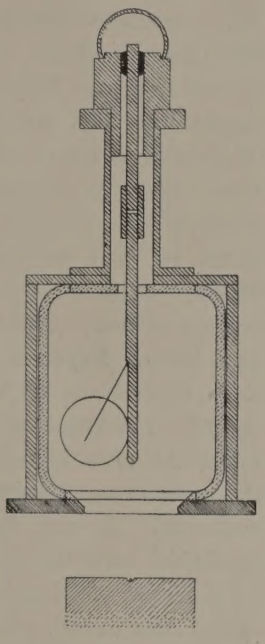

Fig. 1.

The screens to be tested were attached with a little plasticine to the under side of the lead base, the wooden block carrying the radioactive source being so arranged that it could be removed and replaced in the same position. This source consisted of one or more thin glass tubes about 1·5 cm. long by 0·8 mm. diameter, containing emanation, placed in a shallow groove in the block. The activity of the source used varied with the thickness of the screen so as to maintain the rate of motion of the gold leaf within reasonable limits. The screens were placed directly in contact with the electroscope base in order that as large a percentage as possible of the secondary β radiation, emerging at various angles from the upper surface of the screen, should enter the electroscope. The source was placed only 1·85 cms. below the base in order that the divergence of the γ rays passing through the parts of the base surrounding the window might reduce the error due to these rays to a negligible quantity. An allowance was made for the gelatine film in estimating the thickness of the various screens. Experiments with a second film indicated that the absorption of unscreened radiation by such a film amounted to about 6 per cent., so this allowance was made in estimating the effect of a bare emanation tube. In all cases the thickness of the screens used was found by weight.

Secondary Radiation.

The secondary radiation from various substances was compared by the usual method of using a compound screen of two or more materials thick enough to stop all the primary β rays, and observing how the ionisation current varied with the material which was next the window. It is of course necessary that the individual screens should be thick enough to emit their full secondary radiation. In this way the combined effect due to both γ rays and secondary β rays from the screen is directly measured. No appreciable difference could be detected between copper, zinc, brass, iron, tin, or silver. Taking the ionisation current due to γ rays and secondary β rays from any of these screens as 100, that with an aluminium screen was 105, with leather 3 mm. thick 110, and with lead 112. These results are in accord with those of previous investigators, who have found that the "emergence" secondary radiation is a minimum for an atomic weight of about 80.[1] They show that it is best to use some such metal as brass or iron, except where very light screening is required, where aluminium is the most convenient. In this case the presence of copious primary β radiation renders the secondary β radiation of small importance. Experiments were also made with a brass screen about 3 mm. thick, covered on top with different thicknesses of material of low atomic weight. For small thicknesses visiting-cards (0·040 gram per sq. cm.) were found the most suitable, six of them being almost exactly equivalent to the same mass of leather. For greater thicknesses sheets of leather were employed. It was found that adding successive cards increased the ionisation until the total thickness of card or leather amounted to about 0·3 gram per cm. [equivalent to about 3 mm. of tissue]. Further increase caused a slight fall, due to absorption of γ rays. This apparently suggests that the practice of placing a material such as chamois between the metal screen and the skin is unwise; but, when allowance is made for the effect of distance, it will be shown later that this is not so. Practical experience confirms this latter view, as it is found that the presence of a sheet of chamois between the screen and the skin reduces the burning of the latter.

Stopping Power of various Substances.

The results of tests on various materials are shown by the curves in fig. 2, where the ordinates represent activity, and the abscissae mass per unit area of screen.

[1] E.g. Hackett, Scient. Trans. R.D.S., ix, Series II. 9, 1909.

Three curves are shown for card and leather, whose absorption per unit mass is almost identical. In curve *A* the activity of the bare tube is taken as 100, and each unit on the horizontal axis represents 1 gram per sq. cm.

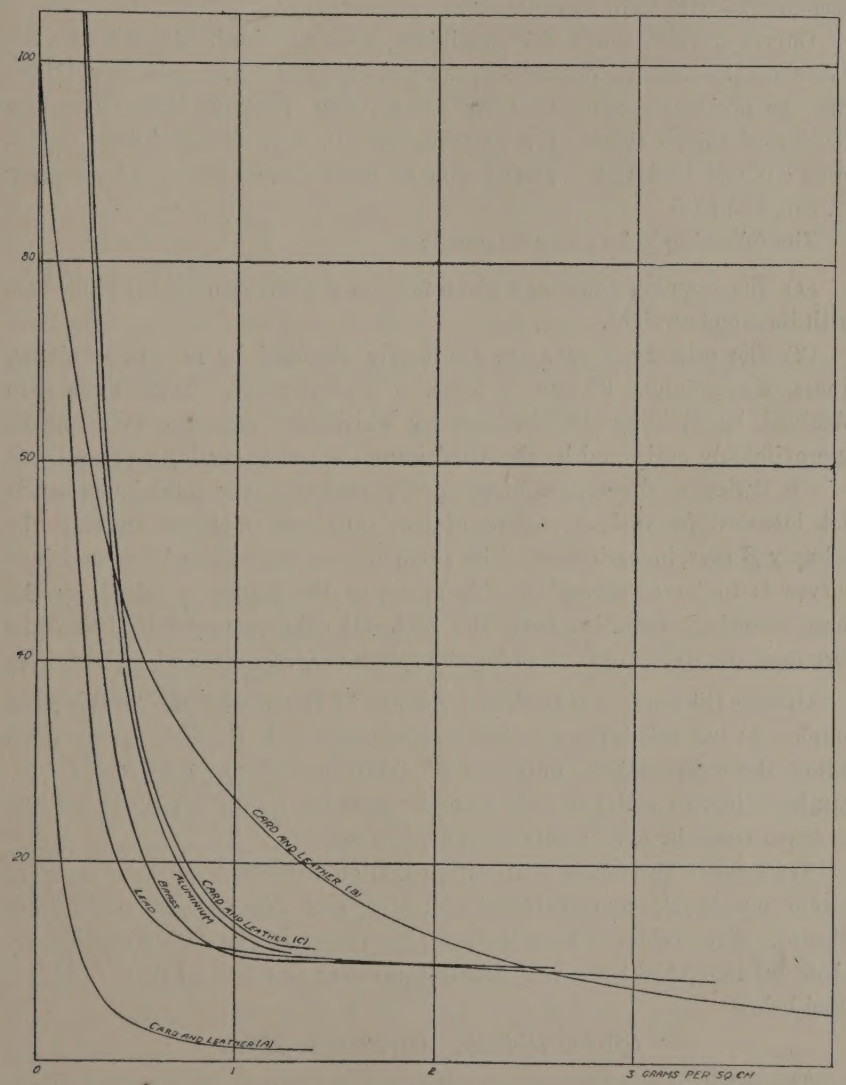

FIG. 2.

[i.e. 1 cm. of animal tissue approximately]. The initial absorption of β rays is better shown on curve *B*, in which the horizontal scale is 10 times as open, i.e. for this particular curve each unit represents 0·1 gram per sq. cm. [1 mm

of tissue]. In curve *C* the vertical scale is 10 times as open, i.e. the activity of the bare tube is now 1000. The horizontal scale is normal. The use of these varying scales is rendered necessary by the great range of activities encountered with light screens.

Curves are also shown for aluminium, brass, and lead. In each case the scales are the same as for curve *C*, the activity of the bare tube being 1000, and the horizontal unit one gram per sq. cm. In using these curves the density of animal tissue may be taken as 1·0, that of aluminium as 2·7, brass 8·0, and lead 11·3. Thus 1 mm. of brass corresponds to 0·8 gram per sq. cm., and so on.

The following points may be noted:—

(1) The stopping power of a given mass of the screen for β rays increases with its atomic weight.

(2) The primary β rays are completely absorbed by 14 mm. of tissue, 5 mm. of aluminium, 1·5 mm. of brass, or 1 mm. of lead. These figures are obtained by dividing the abscissae for which the various curves become approximately horizontal by the densities of the corresponding screens.

(3) Owing to differences in secondary radiation, the total ionisation is not identical for various screens of just sufficient thickness to stop the primary β rays in each case. The peculiar crossing of the brass and lead curves is to be attributed to this cause, as the latter is raised by the large secondary radiation from the lead. It subsequently falls below the former again, owing to the greater absorption of γ rays by lead.

Greater thicknesses of leather could not be tested with the arrangement employed; but this is not a serious disadvantage, as in the calculations which follow the comparatively unimportant absorption of γ rays at such depths can be estimated with sufficient accuracy from the results obtained for brass, or taken from the figures obtained by other workers.

Tests were also made with an emanation tube enclosed in a standard serum needle 1·2 mm. external diameter, and various card and leather screens. These showed that the stopping power of the needle (apparently about 0·1 mm. thick) was very nearly equivalent to 1 mm. of tissue. This is used below.

Effect of Distance. Capillary in Needle.

The effect in the tissues at various distances from a needle containing an emanation tube has been calculated, and is shown in column A of the table on p. 475, in which a represents the distance from the centre of the needle. In making this calculation the emanation, instead of being distributed throughout a tube 15 mm. long by 0·6 mm. internal diameter, is

assumed to be concentrated at 15 axial points one millimetre apart. The stopping power of the wall of the serum needle is assumed to be equivalent to 1 mm. of flesh for normal rays, and proportionally more for oblique rays. For the latter the extra thickness of glass traversed must also be allowed for. Weighing showed that 0·1 mm. is a fair figure to assume for the thickness of wall of a typical emanation tube, as issued by the Royal Dublin Society Radium Institute. This is equivalent to 0·25 mm. of flesh. The outside radius of the serum needle being 0·6 mm., the total absorption between a point O on the axis and a point P at a radial distance a from O in the tissue is equivalent to that of $a + 1{\cdot}25 - 0{\cdot}6$, i.e. $a + 0{\cdot}65$ mm. of flesh. This is equivalent to the bare tube plus $a + 0{\cdot}4$ mm. of flesh. For another axial point O' distant b mm. from O we have distance

$$O'P = \sqrt{a^2 + b^2} \text{ and "equivalent" distance } = \frac{O'P}{a}(a + 0{\cdot}65) - 0{\cdot}25.$$

We look up the corresponding transmission factor from the "leather" curve, taking the unscreened activity as 1000, and multiply this by $\frac{m}{O'P^2}$, where m is the number of millicuries per mm. of the tube.

Summing the results for the 15 axial points, we obtain the activity for any given point P. The units are such that the activity due to one millicurie at one millimetre distance, with no other screening than the normal screening of the emanation tube wall, is 1000. The figures in the table are calculated for points opposite the centre of the capillary, so that the axial points considered, with the exception of the central one, occurred in pairs, thus simplifying the arithmetic.

Effect of Distance. Thick Surface Applicator.

A type of applicator which is considerably used in Dublin consists of a rectangular box made of brass, 3 mm. thick, the internal dimensions being 30 × 20 × 0·6 mm. To the inner surface of this a number of emanation tubes are fixed, with a little wax so as to give as uniform a distribution of activity as possible over the available area of 6 sq. cms. As the diameter of these tubes is about 0·8 mm., we may (making a small allowance for the wax) assume that the centre of the tube is 3·5 mm. from the nearer outer face of the box, and 8·5 mm. from the further outer face.

In estimating the activity at various depths due to such an applicator in contact with the skin the following approximations are made to simplify the calculation :—

(1) The box is assumed to be circular, of such a diameter so as to have the same area, and the calculations made for axial points only.

(2) The emanation is assumed to be confined to a plane parallel to the face of the box in contact with the skin.

(3) The activity of a parallel beam of rays which penetrate the box is assumed to be a linear function of the extra distance traversed. This will not introduce a large error for distances up to 10 cms. of tissue if a suitable absorption coefficient is chosen.

(4) Scattering is neglected [as in previous calculation].

Let r be the radius of the box, t its thickness, b the distance from the inner face of the box to the radioactive layer, and I the surface-density in millicuries per sq. mm.; then obviously the activity at an axial point a mm. below the surface is equal to

$$\int_0^r \frac{[K - (k_1 t + k_2 a)\sec\theta]\, 2\pi I x\, dx}{(b + t + a)^2 \sec^2\theta},$$

where

$$\tan\theta = \frac{x}{b + t + a},$$

and K, k_1, and k_2 are constants defining the absorption in brass and tissue.

Hence

$$\text{Activity} = 2\pi I \int_0^{\phi} [K - (k_1 t + k_2 a)\sec\theta]\tan\theta\, d\theta$$

$$= 2\pi I [K \log_e \sec\phi - (k_1 t + k_2 a)(\sec\phi - 1)],$$

where

$$\tan\phi = \frac{r}{b + t + a}.$$

This expression can be evaluated rapidly and with sufficient accuracy by means of a slide-rule, provided that ϕ—the angle subtended by the radius of the radioactive disc at the given point—is not too small. For small values of ϕ it is best to substitute

$$\frac{\tan^2\phi}{2} - \frac{\tan^4\phi}{4} \quad \text{for} \quad \log_e \sec\phi,$$

and

$$\frac{\tan^2\phi}{2} - \frac{\tan^2\phi}{8} \quad \text{for} \quad (\sec\phi - 1).$$

For very small values the expression reduces to

$$\pi I \tan^2\phi\, [K - (k_1 t + k_2 a)].$$

From inspection of the curves in fig. 2, and consideration of the known rate of absorption of the complex γ rays from *RaB* and *RaC*, we find $K = 10{\cdot}56$, $k_1 = 0{\cdot}32$, and $k_2 = 0{\cdot}04$ (assuming the mass coefficient of

absorption of brass and animal tissue for γ rays to be approximately the same). In all cases considered $t = 3{\cdot}0$ mm.

The figures so obtained would represent the activity if the secondary radiation in the flesh were identical with that on the skin in contact with a brass radiator, as K was determined from the "brass" curve. In the interior the increased secondary radiation due to the tissue raises the total activity by about 10 per cent., so in the results shown below this correction has been applied to all depths exceeding 3 mm. Appropriate corrections are applied for smaller depths, no correction being required at the surface.

Three sets of figures have been worked out and are shown in columns B, C, and D of the following table, the corresponding conditions being explained below:—

a	A	B	C	D	a	A	B	C	D
mm.					mm.				
0	—	1·24	0·62	0·093	15	0·46	0·225	0·15	0·053
0·5	—	1·18	0·60	0·093	16	0·41	0·205	0·14	0·051
0·6	620	—	—	—	17	0·37	0·19	0·13	0·049
1	227	1·12	0·58	0·093	18	0·33	0·175	0·12	0·047
2	58	0·99	0·525	0·091	19	0·30	0·16	0·115	0·045
3	23	0·87	0·475	0·088	20	0·27	0·15	0·105	0·044
4	11·6	0·76	0·425	0·084	25	0·17	0·105	0·076	0·037
5	6·7	0·66	0·375	0·080	30	0·117	0·075	0·058	0·031
6	4·2	0·58	0·31	0·077	35	0·084	0·057	0·044	0·026
7	2·8	0·52	0·305	0·074	40	0·064	0·044	0·036	0·022
8	1·93	0·46	0·275	0·071	45	0·050	0·035	0·030	0·019
9	1·41	0·405	0·25	0·068	50	0·039	0·027	0·023	0·016
10	1·08	0·36	0·23	0·065	60	0·026	0·019	0·016	0·012
11	0·87	0·325	0·21	0·062	70	0·018	0·014	0·012	0·009
12	0·72	0·295	0·195	0·060	80	0·013	0·010	0·009	0·007
13	0·61	0·27	0·18	0·057	90	0·010	0·008	0·007	0·006
14	0·53	0·245	0·165	0·055	100	0·008	0·006	0·005	0·004

Explanation of Table.

a is the distance in millimetres of the point in the tissue at which the activity is given in the other columns. For the figures in column A (emanation needle) a is the distance from the axis of the needle; for the other columns, a is the distance from the surface of the skin.

The activity due to a point-charge of one millicurie at a distance of one millimetre, with no screening except the glass of the emanation tube, is taken as 1,000.

A. Activity due to 10 mc. in a tube 15 mm. long inside a standard serum needle.

B. Activity due to 10 mc. uniformly distributed over 6 sq. cm., the emanation tubes being attached to the bottom of the brass box, 3 mm. thick, which is placed in contact with the skin.

C. Activity due to 10 mc. uniformly distributed over 6 sq. cm., but with the emanation tubes attached to lid of the box, leaving an air space of 5 mm. between the tubes and the inner surface of the bottom of the box.

D. Activity due to 10 mc. uniformly distributed over 100 sq. cm., the tubes being placed as in C.

General Conclusions.

It is evident that the conditions specified under D could not be conveniently realized with a single application; but a similar (though not an identical) effect can be obtained by successive applications of the brass box, covering all parts of the required area in succession for equivalent times. The total dose of millicurie hours must then be used in arriving at the resultant action. For example, if we take the figures in the table as measuring the effect produced by a ten-millicurie-hour dose, the effect of a total dose of 200-millicurie-hours uniformly distributed over 100 sq. cms. would be 20 times the corresponding figure in column D.

The following points may be noted from the above figures:—

(1) The very great activity of emanation in needles at moderate distances.

(2) The great reduction in surface effect caused by increasing the distance of the capillaries from the skin.

(3) The still greater reduction in surface effect due to increase of area.

The effect of interposing material such as chamois between the applicator and the skin is nearly, but not quite, obtained by measuring "a" from the outer surface of the chamois, i.e. by treating the chamois as the outer layers of tissue in the above table. Thus, with conditions B above and 1 mm. of chamois interposed, the activity on the surface of the skin would be 1·12 instead of 1·24. This shows the effect of chamois in acting as a distance piece.

This is not quite accurate, as chamois, being much less dense than living animal tissue, the increase in secondary radiation is much slower in it, so

that the activity at the base of a sheet 1 mm. thick would be less than 1·12. It would appear that the more porous the material used between the metal and the skin the less should be the burning effect upon the latter.

In the case of treatment with several parallel needles, each containing a tube 15 mm. long, the distribution of activity in a perpendicular plane through their centres can be found by summing the effects of the separate needles for any required point. Where the area of irradiation is increased by the use of long needles, which are partially withdrawn at intervals, so as to move the emanation tube to a new position on the axis, the effect is similar to that of a long emanation tube, and could be calculated by the same method as that used above for the short tube.

XXXVI.

THE INFLUENCE OF FEEDING ON MILK FAT.

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[Read February 28. Published April 13, 1922.]

Each individual species of mammal produces milk of composition peculiar to its own group, but among domesticated animals the proportion of some of the constituents, especially that of fat, to the total milk yield varies considerably in the different varieties of each species, in the different strains inside a variety, and, further, even in the individuals of any single strain. The variation in the percentage of fat in the milk of cows and goats, for instance, is practically due to the selection exercised by man; indeed it has long been recognised that selection is the principal method available to the stock-breeder for raising milk fat percentage.

The influence of feeding on milk fat has been the subject of frequent investigation, but very little precise information on the subject is available. Speir [1894, 6 and 7] compared a large number of rations, all liberal in quantity, with one another for the purpose of milk and butter fat production in the dairy cow, and came to the general conclusion that the criterion of efficiency in a ration is its total dry matter. But he was of opinion that some foods tend to increase the milk yield, while others tend to increase the milk fat principally. Fresh grass and brewers' grains, he states, tend to increase the milk yield at the expense of the percentage of butter fat; on the other hand, vetches and decorticated cotton cake tend to increase the percentage of fat at the expense of milk yield. It is significant that both of these foods contain a high proportion of protein; in fact, Speir concludes that rations with a very high albuminoid ratio seem to have a depressing effect on the milk yield. On the other hand, Crowther [1906], reviewing the work done in Great Britain for some years previously, makes the following statement: "Such changes as may possibly be effected in the quantitative composition of milk by change of food are only very slight, provided, of course, the rations prior and subsequent to the change are suitable in nature and in quantity." Wing and Foord [1904] record an attempt to increase the fat in milk by means of liberal feeding, and state that in a herd of poorly

fed cows the subsequent feeding of an abundant ration resulted in an increase in the percentage of fat as well as an increase in the total milk and total fat. The experiment continued over a number of years. Yet Rühle [1919] and Pritzker [1919] find, from a large number of analyses made during the period 1914–18, no evidence to show that food deficiency causes a decrease in the fat content of milk. Data collected by the Dairy Section of the Department of Agriculture and Technical Instruction for Ireland does not lend support to this view, but is rather in agreement with the work of Wing and Foord. Referring to the effect of water in the food on the composition of milk, Turner, Shaw, Norton, and Wright [1916] state that the water content of a ration has no effect on the composition of milk yielded therefrom; and Berry [1921] comes to the same conclusion. It is evident that there is no unanimity of opinion among previous investigators as to the effect of feeding on milk fat.

Much of the work referred to was done on good condition cattle, continuously getting abundant supplies of food, so that the effect of the changes in diet was difficult to detect. Besides, changes were made by completely substituting one food for another, so that usually more than one food constituent was involved. For instance, the substitution of brewers' grains for cotton cake involves a change in the quantity of carbohydrates and fats, and in the quantity and quality of the proteins. Thus more than one variable was introduced, and there was not a clear comparison of the effect of one food ingredient with that of another. Realizing the necessity for conducting such an investigation under conditions approximating to laboratory control, it was decided in this investigation to substitute goats for cows. To the diet of these animals the individual food constituents could be added at comparatively small cost, while at the same time sufficient milk is yielded to afford a considerable margin for fluctuation resulting from experimental changes in conditions. In the goat, as in the cow, the milk yield is highest at the beginning of lactation, and it declines gradually towards the end. The lactation period, in the case of the old Irish breed, usually begins in April and terminates about December. As in the cow also the percentage of fat in the milk tends to increase as lactation advances, and the weight of the animal's body similarly increases towards the termination of the milk flow, especially with liberal feeding. The general procedure in this investigation was first to observe the quantity of food which just maintained the animal's weight and at the same time yielded a constant flow of milk, and then test the effect of adding to this "milk and body maintenance" ration different quantities of individual food constituents. Then, when the effect of an addition to the ration was determined, the effect of the withdrawal of that addition was subsequently investigated. Extra food assimilated above the "milk and

body maintenance" level goes to increase either the milk, or some of the constituents thereof, or the weight of the animal, or all three. Consequently right through the period of investigation records were kept of milk, milk fat, and the animal's weight. The milk was weighed and the fat percentage determined daily, and the animals were regularly weighed once a week.

Figs. 1, 2, and 3 record the diet and changes therein of three experimental goats during the period of investigation, and give a graphical representation of the results from the experiment.

The results obtained from this investigation are interpreted as follows :—

GOAT 1.

1. Reduction in daily ration (change from ration A to B) produces—
   (*a*) No change in milk yield ; as a matter of fact, the already increasing yield continues to increase for a short time.
   (*b*) Reduction in daily per cent. fat of 1·25 (4·75 to 3·5).
   (*c*) Reduction in daily total fat of 0·015 lb. (0·130 to 0·115).

2. Addition of 0·47 lbs. soya fat to daily ration (change from ration B to C) produces—
   (*a*) No change in milk yield.
   (*b*) Increase in daily per cent. fat of 0·75 (3·5 to 4·25).
   (*c*) Increase in daily total fat of 0·035 lb. (0·115 to 0·150).

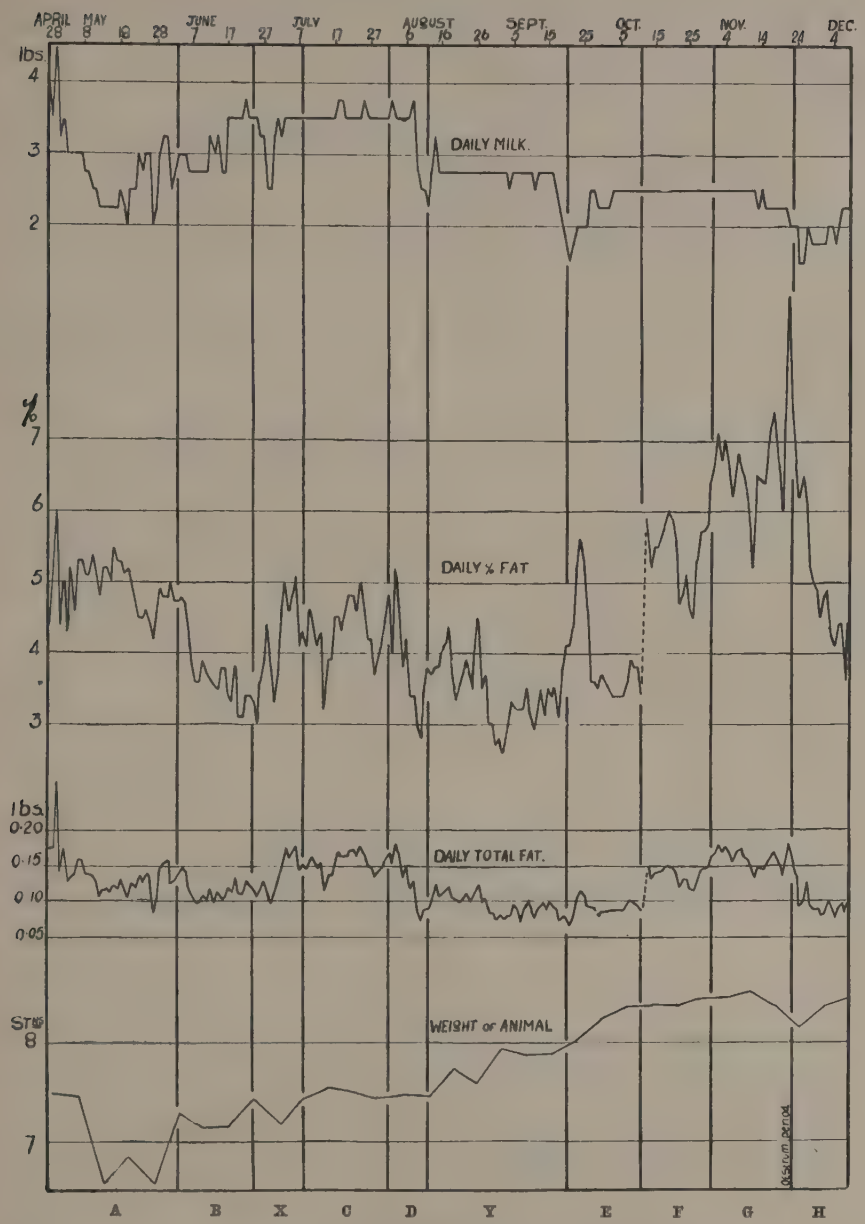
2_1. Withdrawal of roots from ration (change from ration C to D) produces—
   (*a*) Considerable reduction in milk yield.
   (*b*) „ „ daily per cent. fat.
   (*c*) „ „ daily total fat.

3. Addition of 0·5 lbs. soya fat to daily ration (change from ration E to F) produces—
   (*a*) No change in milk yield.
   (*b*) Increase in daily per cent. fat of 1·75 (3·75 to 5·5).
   (*c*) Increase in daily total fat of 0·05 lb. (0·09 to 0·14).

4. Further addition of 0·5 lb. soya fat to daily ration (change from ration F to G) produces—
   (*a*) No change in milk yield.
   (*b*) Increase in daily per cent. fat of 1·0 (5·5 to 6·5).
   (*c*) Increase in daily total fat of 0·025 lb. (0·140 to 0·165).

5. Reduction in daily ration (change from ration G to H) produces—
   (*a*) No change in milk yield.
   (*b*) Reduction in daily per cent. fat of 2·0 (6·5 to 4·5).
   (*c*) Reduction in daily total fat of 0·075 lb. (0·165 to 0·090).

Fig. 1—Goat 1.



Daily Ration.

A—(37 days). Hay ad lib. Mangels, 1 stone. Crushed oats, bran, and dried grains, 1½ lbs.

B—(21 days). Hay, 1 lb. Mangels 10 lbs. Skim-milk powder, 1·28 lbs. [Reduction on previous ration.]

X—(14 days). (Transition to new ration.)

C—(24 days). Hay, 1 lb. Mangels, 10 lbs. Skim-milk powder, 1·28 lbs. Fat (soya), 0·47 lb. [0·47 lb. soya fat added to previous ration.]

D—(11 days). Hay, 1 lb. Skim-milk powder, 1·28 lbs. Fat (soya), 0·47 lb. [Withdrawal of roots from ration.]

Y—Irregular, owing to failure of supplies.

E—(21 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb.

F—(20 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. Fat (soya), 0·5 lb. [0·5 lb. soya fat added to previous ration.]

G—(23 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. Fat (soya), 1·0 lb. [0·5 lb. soya fat added to previous ration.]

H—(17 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. [Reduction on previous ration.]

GOAT 2.

1. Reduction in daily ration (change from ration A to B) produces—

(*a*) No change in milk yield.
(*b*) Reduction in daily per cent. fat of 0·25 (3·75 to 3·5).
(*c*) Reduction in daily total fat of 0·015 lbs. (0·135 to 0·120).

2. Addition of 1·06 lbs. wheaten starch to daily ration (change from ration B to C) produces—

(*a*) No change in milk yield.
(*b*) Increase in daily per cent. fat of 0·75 lbs. (3·5 to 4·25).
(*c*) Increase in daily total fat of 0·03 lbs. (0·12 to 0·15).

3. Addition of 1·13 lbs. wheaten starch to daily ration (change from ration E to F) produces—

(*a*) No change in milk yield.
(*b*) Increase in daily per cent. fat of 0·75 (5·0 to 5·75).
(*c*) Increase in daily total fat of 0·02 lbs. (0·125 to 0·145).

3_1. Substitution of 0·5 lbs. fat for 1·13 lbs. starch (change from ration F to F_1) produces—

(*a*) No change in milk yield.
(*b*) Increase in per cent. fat.
(*c*) „ total fat.

The fact that this increase is of short duration, and that the yields tend to return to original level, discounts this result.

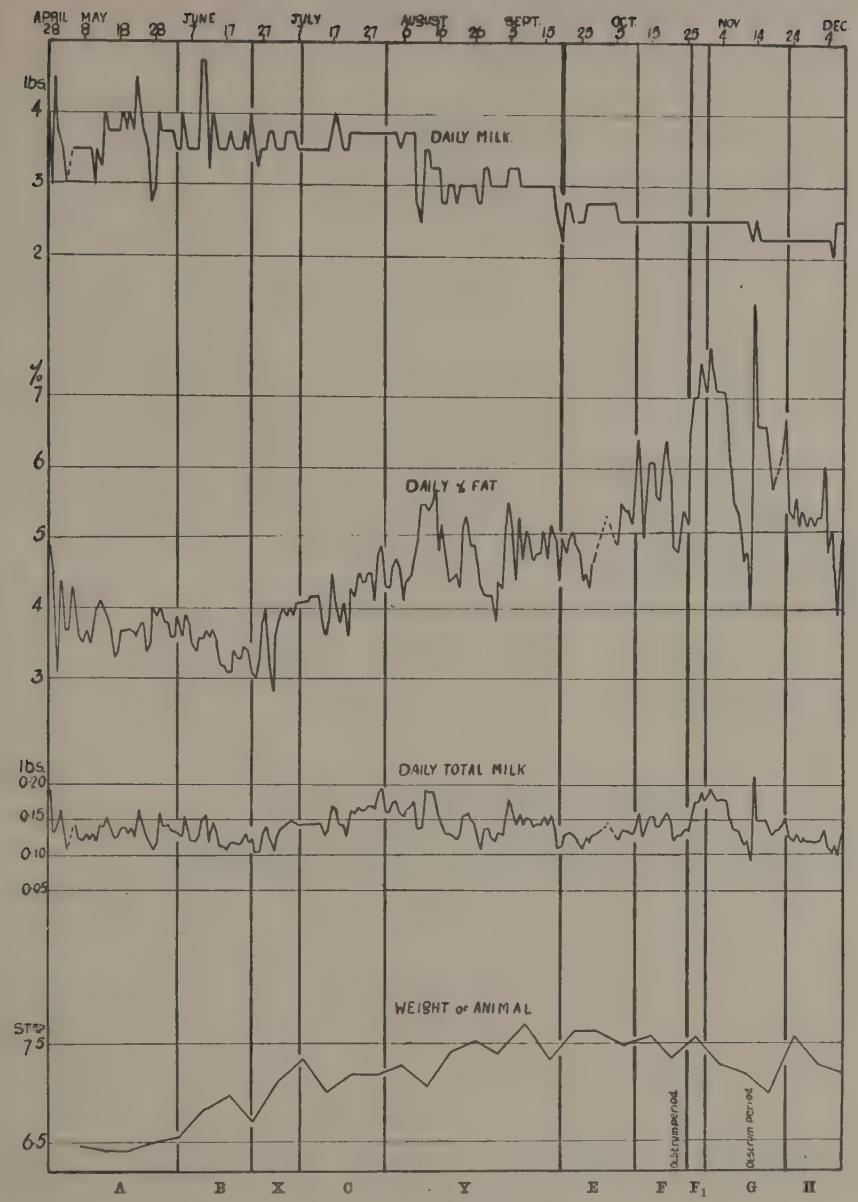
4. Substitution of 1·13 lbs. casein for 0·5 lbs. fat, and hence for 1·13 lbs. starch (change from ration F_1 to G), produces—

(*a*) No change in milk yield as compared with ration F.
(*b*) „ „ daily per cent. fat „ „ „ „
(*c*) „ „ daily total fat „ „ „ „

5. Reduction in daily ration (change from ration G to H) produces—

(*a*) No change in milk yield.
(*b*) Reduction in daily per cent. fat of 0·5.
(*c*) Reduction in daily total fat of 0·025 lbs. (0·145 to 0·120).

Fig. 2—Goat 2.



Daily Ration.

A—(37 days). Hay ad lib. Mangels, 1 stone. Crushed oats, bran, and dried grains, 1½ lbs.

B—(21 days). Hay, 1 lb. Mangels, 10 lbs. Skim-milk powder, 1·28 lbs. [Reduction on previous ration.]

X—(14 days). (Transition to new ration.)

C—(24 days). Hay, 1 lb. Mangels, 10 lbs. Skim-milk powder, 1·28 lbs. Starch (wheaten), 1·06 lbs. [1·06 lbs. starch added to previous ration.]

Y—Irregular, owing to failure of supplies.

E—(21 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb.

F—(20 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. Starch, 1·13 lbs. [1·13 lbs. starch added to previous ration.]

F1—0·5 lb fat replaces the starch of previous ration.

G—(23 days). Hay, 1 lb Turnips, 10 lbs. Oats, 0·83 lb. Casein, 1·13 lbs. [1·13 lbs. casein replaces the 0·5 lb. fat of previous feed, and the 1·13 lbs. starch of the ration previous to that.]

H—(17 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. [Reduction on previous diet.]

GOAT 3.

1. Reduction in daily ration (change from ration A to B) produces—

(*a*) No change in milk yield.
(*b*) Reduction in daily per cent. fat of 0·75 (4·0 to 3·25).
(*c*) Reduction in daily total fat of 0·02 lb. (0·175 to 0·150).

2. Addition of 0·5 lb. butter fat to ration (change from ration B to C) produces—

(*a*) No change in milk yield.
(*b*) Increase in daily per cent. fat of 1·0 (3·25 to 4·25).
(*c*) Increase in daily total fat of 0·04 lb. (0·15 to 0·19).

3. Addition of 1·13 lbs. casein to daily ration (change from ration E to F) produces—

(*a*) No change in total milk yield.
(*b*) Increase in daily per cent. fat of 0·75 (4·5 to 5·25).
(*c*) Increase in daily total fat of 0·025 lb. (0·110 to 0·135).

4. Further addition of 0·5 lb. fat to daily ration (change from ration F to G) produces—

(*a*) No change in milk.
(*b*) Increase in daily per cent. fat of 1·0 (5·25 to 6·25).
(*c*) Increase in daily total fat of 0·025 lb. (0·135 to 0·160).

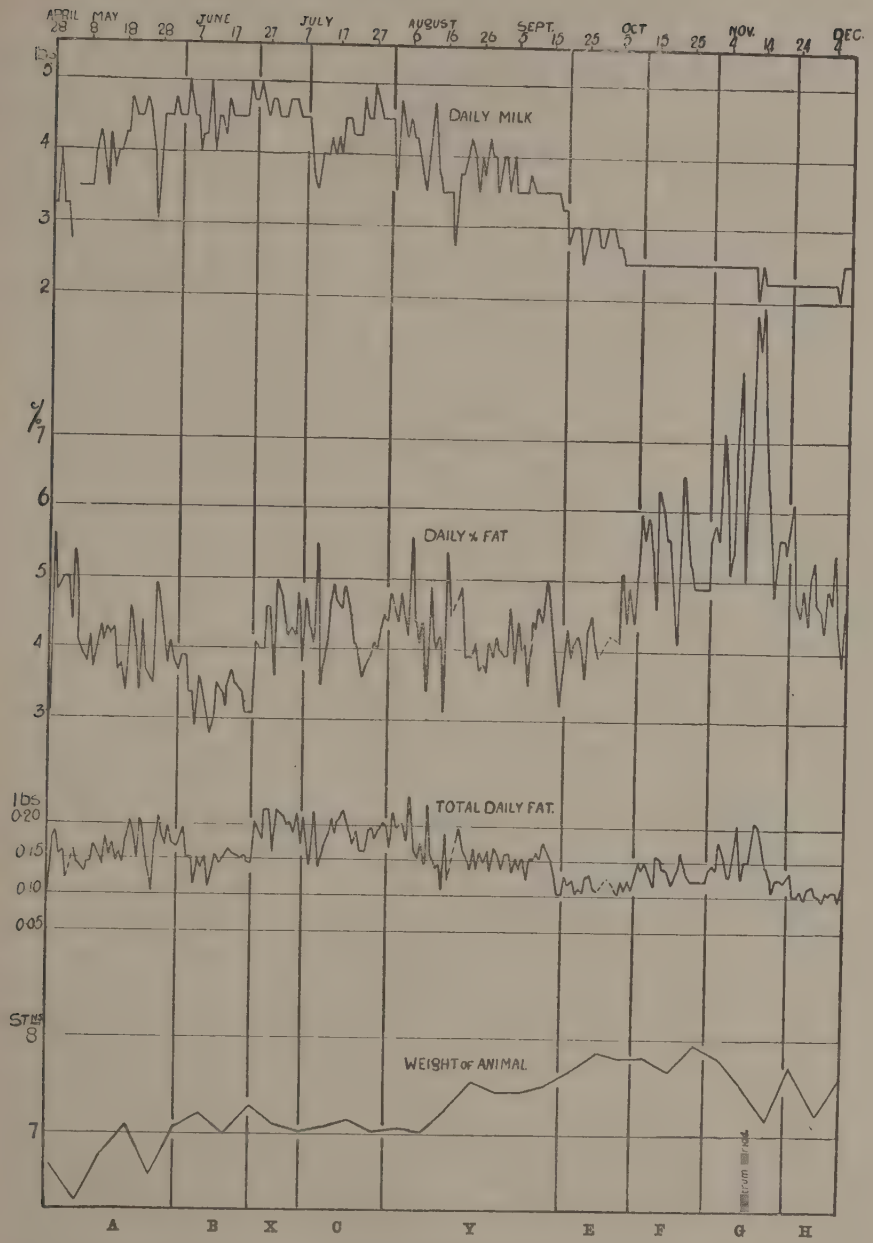
5. Reduction in daily ration (change from ration G to H) produces—

(*a*) No change in milk yield.
(*b*) Reduction in daily per cent. fat of 1·5 (6·25 to 4·75).
(*c*) Reduction in daily total fat.

The foregoing results lead to the following conclusions:—

1. By considerably reducing the ration the total daily yield of fat is reduced. If, at the same time, there is little or no reduction in milk yield, the percentage of fat in the milk is lowered. This occurs in the early stages of lactation, when the mammary gland is very active, and towards the end of the lactation, when the milk flow is already reduced to a minimum. Obviously, a fall in milk yield, accompanied by a fall in total fat, may leave the percentage of fat unchanged; and conceivably a considerable fall in milk occurring at the same time as a reduction in total fat may produce an increase in the percentage of fat in the milk.

Fig 3—Goat 3.



Daily Ration.

A—(37 days). Hay ad lib. Mangels, 1 stone. Crushed oats, bran, and dried grains, 1½ lbs.

B—(21 days). Hay, 1 lb. Mangels, 10 lbs. Skim-milk powder, 1·28 lbs. [Reduction on previous ration.]

X—(14 days). (Transition to new ration.)

C—(24 days). Hay, 1 lb. Mangels, 10 lbs. Whole milk powder, 1·75 lbs. [·45 lb. butter fat added to previous ration.]

Y—Irregular, owing to failure of supplies.

E—(21 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb.

F—(20 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. Casein, 1·13 lbs. [1·13 lbs. casein added to previous ration.]

G—(23 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. Casein, 1·13 lbs. Fat, 0·5 lb. [0·5 lb. fat added to previous ration.]

H—(17 days). Hay, 1 lb. Turnips, 10 lbs. Oats, 0·83 lb. [Reduction on previous ration.]

2. By adding butter fat, soya fat, wheaten starch, or casein to a "milk and body maintenance" ration the total fat in the daily milk is increased. In all the tests recorded in this investigation the milk flow remains unaffected by the addition of these single food substances; but the percentage of fat in the milk is increased. That is to say, the percentage of fat in the milk is raised, not only by the addition of fat to the food, but also by the addition of carbohydrate or protein. Obviously, if an increase in the milk flow occurs proportionate to the increase in the total fat, the percentage of fat in the milk is unchanged.

3. In the production of butter fat in milk, starch, casein, and fat (both butter and soya) replace one another; but the quantities which replace each other cannot yet be definitely stated. In the early part of lactation 0·45 lb. of soya fat produced an increase of 0·035 lb. of fat in the milk of goat 1; 1·06 lb. starch (that is about two and a quarter times more starch than fat) produced an increase of 0·03 lb. milk fat in goat 2; and 0·45 lb. butter fat produced an increase of 0·04 lb. milk fat in goat 3. In the second half of lactation 0·5 lb. soya fat produced an increase in the total milk fat of 0·05 lb. in goat 1, 1·13 lb. starch (about two and a quarter times the weight of fat), an increase of 0·02 lb. milk fat in goat 2, and 1·13 lb. casein an increase of 0·025 lb. milk fat in goat 3. In one case soya fat was just slightly better and in another it was twice as good as two and a quarter times its weight of starch. Butter fat was slightly better than soya fat for milk fat production, but the test was too limited to draw a general conclusion. It was thought that butter fat would be much superior for this purpose to soya fat, because of its content of vitamin A; but perhaps sufficient vitamin A was already supplied in the remainder of the ration to prevent a possible difference between the effects of the two fats becoming apparent.

In goat 2 the substitution of fat for starch in ration F_1 had a peculiar result. Possibly this is temporary, and the duration of this test was too short to allow of a general conclusion. When, however, casein replaces the fat (ration G, goat 2), the total fat in the milk is similar to that produced by an equal weight of starch. Thus right through the experiment casein and starch replace one another in equal proportions. Evidently this can only hold where sufficient protein is already supplied in the "milk and body maintenance" ration to contribute to the production of the protein moiety of the milk yielded, and otherwise maintain nitrogenous equilibrium. Further work remains to be done on the quantitative replacement of fats and carbohydrates in food for the purpose of milk fat production.

4. While an addition to the "milk and body maintenance" ration

increases the butter fat, a further similar addition does not increase the butter fat to the same extent. In goat 1, the addition of half a pound of fat to the ration (ration E to F) increased the milk fat by 0·05 lb.; a further addition of half a pound caused an increase of only 0·025 lb. milk fat. Even where the diet already contains a large proportion of protein (ration F, goat 3) the further addition of half a pound of fat to the diet gave an increase of only 0·025 lb. milk fat. The percentage of fat in milk can obviously be raised by extra feeding to a maximum; and, if fat percentage is the only consideration, it might be said that the maximum is reached according to the law of diminishing returns. But, as the ration is increased, body weight and total milk may be also increased, and a successively larger proportion of the food utilized for these purposes. Since, according to Nils Hansson [1916] and Wilson [1920], the law of diminishing returns does not hold in the production of beef and milk, neither is it likely to hold in the production of butter fat.

Summary.

In the case of a lactating goat—

1. A considerable reduction in the ration may cause a decrease in the percentage of fat in the milk. This occurs when the total fat yield is decreased at the same time as the milk yield remains unchanged, or when the proportionate decrease in the total fat is greater than the decrease in milk.

2. The addition of a concentrate to a ration may cause an increase in the percentage of fat in milk. This occurs when the total fat yield is increased, while the milk yield remains unchanged, or when the proportionate increase of total fat is greater than the increase in milk.

3. In effecting an increase in the total and in the percentage of butter fat in milk, starch, fat (soya and butter), and protein can replace one another. After the necessary minimum of protein is supplied, starch and casein replace one another for that purpose in equal parts.

4. There is a maximum milk fat percentage, and, as this limit is approached, the extra food added to the ration produces a successively decreasing addition to the milk fat percentage, but at the same time a successively increasing addition to the body weight or milk yield, or both.

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XXXVII.

ON A NEW METHOD OF GAUGING THE DISCHARGE OF RIVERS.

By J. JOLY, Sc.D., F.R.S., F.T.C.D.

[Read February 28. Published April 13, 1922.]

The new method is based on the principle underlying "chemical hydrometry." This principle may be simply expressed as follows:—

Suppose it were required to estimate the quantity of water contained in a large tank the volume of which it was difficult to determine by mere geometric measurements. By means of chemical hydrometry the quantity of water is easily found. A known weight of any suitable soluble salt is stirred into the tank, so that there is uniform distribution of the salt throughout the water. We then abstract a known volume V of the water, and by titration or other means estimate how much of the salt is contained in this volume of water. Now, if this amounts to $\frac{1}{n}$th of the salt put into the tank, the volume of water in the tank must be $n \times V$.

This method has been applied to the discharge of rivers. A tank is erected at some convenient point on the river. In this tank a large volume of water is stored, and into it is stirred a heavy charge of the salt; generally chloride of sodium. A pipe is led from the tank into the river, and the salt solution is fed slowly, and at a uniform rate, from the tank, escaping from perforations in the pipe and intermingling with the current. At a point some distance down stream samples of water are taken at intervals. These samples are titrated; and, knowing the rate at which the salt has been fed into the river, the rate of discharge can be calculated.

Very accurate results are obtained by this method. The error can be reduced below 1 per cent. It is said to be superior in accuracy to weir-measurements, and very much superior in accuracy to measurements based on current meters. A very full account of the method is given by B. F. Groat, M.Am.Soc.C.E., in the Proceedings of the American Society of Civil Engineers, vol. xli, November, 1915.

A study of Mr. Groat's paper reveals the advantages and disadvantages of the method. Chief of the latter is the cumbersome nature of the preparations which have to be made, due to the large amount of salt required.

Moreover, the cost is considerable, owing to the scale on which the salt must be supplied.

It was in connexion with the important problems arising in relation to Irish water-power utilization, as recently put forward by Sir John Purser Griffith before this Society, that I thought of the following procedure. At the time I was in ignorance of the fact that the principle involved had ever before been used or thought of.

I propose to utilize, in determining river discharge, the extraordinary accuracy with which radioactive measurements can be effected. A very simple form of electroscope suffices to determine a quantity of radium to the billionth part of a gram. The apparatus costs a very few shillings. If, now, in place of introducing salt by the hundredweight into the river, we flow into the river a few litres of a solution containing a trace of radium, and taking samples down stream examine them by the electroscope, the discharge of the river may be determined.

In order to reduce the working conditions to figures, I take the case of the Poulaphuca and Golden Falls on the Upper Liffey. The flow I take as 20,000 cubic feet per minute.

The constant of the electroscope I take as $0{\cdot}54 \times 10^{-12}$. That is to say, this quantity of radium, or rather the emanation in equilibrium with it, will cause the gold leaf of the electroscope to show a gain in rate of fall of 1 scale division per hour. I have made many such electroscopes. We require to know how much radium is to be put into the river, so that we can estimate the discharge to 1 per cent.; and I assume that the feed of radioactive water into the river is maintained for twenty minutes.

Suppose we withdraw samples of 10 litres volume for testing by the electroscope. To evaluate the radium to 1 per cent., it must increase the rate of fall of the leaf of the electroscope by 100 scale divisions per hour. That is, the 10 litres must contain 54×10^{-12} gram radium; i.e., there must be $5{\cdot}4 \times 10^{-12}$ gram radium per litre of water passing down the river. Now, the flow of the river as assumed is about 600,000 litres per minute. The quantity of radium fed in per minute must therefore be $6 \times 10^5 \times 5{\cdot}4 \times 10^{-12} = 32 \times 10^{-7}$ gram. q, p; and for twenty minutes' flow we require 64×10^{-6} gram radium: that is, 0·064 milligram must be put in.

Now, the most economical form in which the radium can be supplied is pitchblende, the mineral oxide of uranium. In this ore 200 milligrams of radium are associated with 1,000 kilos of the mineral, from which we find that 0·01 milligram of radium are contained in 50 grams of the ore. 300 grams are required to supply 0·06 milligram.

This quantity of radium—pure—would cost about 36s.; in the ore it should be one-sixth or one-eighth part of this, i.e., five or six shillings.

If a two per cent. determination was deemed sufficiently accurate, and a fifteen-minute feed into the river, a hundred grams of the crude ore would suffice, and the cost would be correspondingly reduced.

As regards details, I propose to bring the pitchblende into solution by powdering it and adding nitric acid. It dissolves readily. The charge is then diluted with water up to about two gallons, i.e., the full of a petrol tin. In this form it is brought to the scene of operations. The stopper is then replaced by one which carries a copper tube dipping to the bottom of the tin. This tube is coupled to a similar small-bore tube to be laid out across the current. It is pierced with fine holes at intervals, say of 6 inches. Air pumped into the tin by an ordinary tyre-pump serves to expel the liquid. The current is steadied by having in circuit an indiarubber bag, which is kept inflated to a constant pressure, as read by a small air-pressure gauge. The air-pressure being considerable, the small effect of variation in hydrostatic head will be negligible.

I think a very little time spent on experiments in the laboratory will suffice to bring these practical details into working order.

When the samples are collected (each sample will about fill a petrol tin) and brought back to the laboratory, they are stored in ordinary boiling flasks for ten or twelve days. The emanation is then boiled off, being caught in a small exhausted bulb, from which it is introduced into the electroscope. At the end of three hours the electroscope is read, and the river discharge is then immediately deducible. If thought desirable, the samples may be evaporated down to any required extent. No error is introduced by this process. It is necessary to carry out these operations in a laboratory free from radium contamination.

XXXVIII.

ON A VARIETY OF PINITE OCCURRING AT BALLYCORUS, CO. DUBLIN.

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[Read February 28. Published April 13, 1922.]

Introduction.

Some months ago Mr. J. C. Davison, of the Engineering School, Trinity College, Dublin, brought me for identification a green mineral, found at the old lead mines of Ballycorus. It appears not to have been described before.

Mode of Occurrence.

A visit to the locality showed that the substance occurs in the granite blocks thrown out during mining operations, and lying about in and around the large cutting, near the chimney, at the top of the hill. The excavation is at the junction of granite and schist. All stages can be found between typical granite and a thoroughly green rock.

Results of Tests.

The following are the results of tests made on the most translucent, lustrous fragments :—

Compact. Unctuous.

H = 2·5. G = 2·780.

Lustre.—Fatty.

Colour.—Oil green to pale yellowish green. Translucent.

Insoluble, and does not gelatinize in hydrochloric or nitric acide, or n caustic potash.

Decomposed by hot concentrated sulphuric acid, with separation of powdery silica. Alum is deposited when the filtered acid is evaporated.

In the closed tube gives off water easily, and becomes white. Some fragments darken. Occasionally decrepitates slightly.

BB.—Infusible, turns white, and does not colour the flame. With cobalt nitrate gives a strong blue.

Details of Tests.

Hardness tests required special care owing to the presence of minute grains and veins of quartz. The salient angles of chips were used to scratch good cleavage surfaces of selenite, Iceland spar, &c. In one sample, for

instance, there were four convenient angles. Three of these scratched Iceland spar ; the fourth would not. The latter corner scratched selenite.

Measurements of specific gravity were made by means of methylene iodide, diluted with xylol, on very small particles obtained by crushing. The specific gravity of the liquid was found with a Westphal balance. The highest results are considered the most reliable, for (1) the microscope showed that the chief impurity was quartz, and the specific gravity always came out higher than that of quartz ; (2) dull specimens known to be impure gave low results ; (3) the more finely divided material gave a higher proportion of heavy grains.

Chemical Analysis.

The result of a chemical analysis of five or six grams of the most carefully picked material is shown in column I of the table. One chip of the same lot was sliced for the microscope in order to gain an idea of its purity. It contains a remnant of a disintegrating felspar crystal and some minute granules of quartz, but the great bulk of it is of one kind of material of uniform texture.

	I.	II.	III.
SiO_2 . . .	49·54	46	47
Al_2O_3 . . .	34·86	33	32
Iron Oxide . . .	0·24	4	3
CaO . . .	tr.	0	1
MgO . . .	0·72	1	2
Na_2O . . .	0·78	1	1
K_2O . . .	9·00	9·5	8
Li_2O	tr.	—	—
P_2O_5 . . .	?	—	—
CO_2 . . .	0·00	—	—
F . . .	0·00	0·5	—
Moisture . . .	0·90	5	6
Loss on ignition . .	3·90 } 4·80		
	99·94	100	100

I.—Pinite, Ballycorus, Co. Dublin.

II.—Average of 19 analyses of muscovite quoted by Dana (Syst. Min., 6th ed., pp. 617–8, analyses 1 to 19, inclusive. 1911).

III.—Average of 12 analyses of pinite (*loc cit.*, p. 622).

Microscopical Characters.

In thin section the mineral still appears compact when viewed with a pocket lens. With a magnification of seventy diameters it exhibits a granular structure, and appears to have higher refraction than quartz. Between crossed nicols it is seen to be birefringent, the field being finely speckled. A higher power shows that in places the structure consists of rough radial aggregates, in which the components may occasionally be seen to have straight extinction.

Identification.

Comparing the analysis with column II of the table, it will be seen that there is good agreement with an average muscovite. The latter, however, is not affected by acids, whereas the Ballycorus mineral is completely decomposed by hot concentrated sulphuric acid.

The term Pinite is applied to a number of compact substances, which are generally alteration products, and have a composition similar to that of muscovite. Most, if not all, of them differ from muscovite, and agree with our mineral, in being decomposable by sulphuric acid. As was to be expected, since they are generally impure substances, none of the named varieties was found to agree in all points with the Ballycorus mineral, though many come near it.

The best agreement seems to be with pinitoid. That mineral, according to A. Knop,[1] is a basic silicate, mica-like in composition, containing water, decomposable by hot sulphuric acid, micro to cryptocrystalline, of usually earthy to dense compact habit, of a leek-, oil-, or greyish-green to whitish colour, which may pass over into various shades of red. Specific gravity, 2·788 ; H, 2·5. It is a secondary mineral formed by hydration, which frequently occurs as pseudomorphs after felspar in altered porphyry.

So far this might apply to the Ballycorus mineral, except that it was not observed in shades of red. Knop's analysis would account for this, and reveals a considerable difference in composition, for the pinitoid analysed gave 8·84 per cent. oxide of iron against 0·24 per cent. in our mineral. Pinitoid, too, is low in potash, 5·85, as compared with 9·00.

Column III of the table is the mean of the twelve pinite analyses given by Dana.[2] Comparison with column I shows the close agreement. As a matter of fact, all the figures for the Ballycorus mineral are inside the extremes occurring in those analyses.

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[1] " Neues Jahrbuch für Mineralogie," etc., p. 558. 1859.
[2] *Loc. cit.*, p. 622.

The mineral under discussion, then, is evidently a pinite. It seems to me unnecessary to invent any more definite term.

Since killinite, another variety of pinite, occurs, also near the granite margin, at Killiney, a few miles from Ballycorus, we must distinguish it from the present mineral. It differs most distinctly (1) in being pseudomorphous after spodumene, (2) in being fusible before the blowpipe.[1]

Origin and Relations.

A number of thin slices of granite in various stages of alteration were prepared. One fresh-looking specimen contains abundant allotriomorphic microcline, with strong, typical cross-hatching, only slightly cloudy on certain laminae, and often including idiomorphic crystals of the other felspars. There is much albite, mostly speckled over with alteration products. What appears to be orthoclase is much altered, the secondary material usually occupying all the centre of the crystal, and agreeing in appearance with the pinite. The quartz is in groups of grains, and there is a fair amount of muscovite. Cataclastic structures are evident. The quartz is in places finely granular, and the mica bent and broken. In a shear zone the latter seems to be ground to a fine granular paste, which is doubtfully distinguishable in places from the pinite. A little galena is present.

Slices containing a considerable amount of pinite appear to show that it originates, at least chiefly, from felspar. The latter often occurs like an archipelago surrounded by a sea of the alteration product, the islands being optically parallel. In this material the felspars have rather indefinite optical characters. Considerable fragments may appear untwinned, but a higher magnification often reveals the microcline structure on a minute scale in spots, mostly at the edges. What appears to be secondary lamellar twinning is often seen. In several cases there cross such felspars broad bands, suggesting shearing planes, distinguished by more intense alteration. Quartz is generally abundant, often showing strain shadows, which are sometimes arranged fanwise.

A slice made from a piece of rock having a fairly uniform green colour, but a dull lustre, was found to consist of pinite with abundant, but small, ragged quartz grains, a very few similar fragments of felspar, and still fewer of muscovite.

A remarkable relation between quartz and pinite is observed in some

[1] Thos. Taylor, "Account of a New Mineral Substance discovered at Killiney, in the vicinity of Dublin," Trans. Roy. Ir. Acad., vol. xiii, p. 61. 1818.
T. Thompson, "Outlines of Mineralogy," vol. i, p. 330. 1836.

slices, the latter being in rosette-like patches within the quartz grains in the plane of section, or biting into their edges, as if growing at the expense of the quartz. This is extremely unlikely, especially as no trace of fluorine was found in the analysed material, though looked for specially.

It is probable that the silica, thrown out of the felspar as it alters into pinite, crystallises round the latter, and is moulded upon it.

That quartz is so produced is well known. Rosenbusch,[1] referring to orthoclase "altered to muscovite (pinitoid)," states that "quartz is almost always mixed with these pseudomorphs in variable amounts."

[1] "Microscopical Physiography of Rock-making Minerals." Rosenbusch-Iddings, 3rd ed., p. 314. 1893.

XXXIX.

ON THE LIFE-HISTORY AND BIONOMICS OF THE FLAX FLEA-BEETLE (*LONGITARSUS PARVULUS*, PAYK.), WITH DESCRIPTIONS OF THE HITHERTO UNKNOWN LARVAL AND PUPAL STAGES.

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(Plates XV–XIX.)

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1.—Introduction.

Nearly one hundred years ago the flax crop in parts of Ulster was almost completely destroyed while in the seedling stage as a result of the ravages of the small, black, jumping beetle, now known as the flax flea-beetle. During various intervening seasons damage due to the same cause has occurred in many parts of Ireland, and this beetle is now regarded as being by far the most dangerous insect enemy of flax, and one capable of causing losses amounting to many thousands of pounds sterling in a single season.

Like the other members of the family Chrysomelidae, it is herbivorous, feeding in the adult stage on the cotyledons and young leafy shoots of flax seedlings. The destruction of the young plants gives rise to thin, uneven brairds, and the ultimate production of dwarfed, branched, and uneconomic crops of flax; indeed, it is frequently the case that the young seedlings are entirely destroyed and large areas are laid bare, thus necessitating re-sowing.

Flax-growers have long been familiar with the ravages of this pest, which is popularly known as the "fly" or "flea"; but, despite this fact, little work has been done regarding its biology and habits, or possible remedial measures, while no details are available in entomological literature with reference to the general relations of the adult beetles and their larvae with the food plants and the soil in which the latter are growing.

In July, 1920, the writer commenced, at the Department's Field Laboratory for Flax Diseases, Coleraine, Co. Derry, an investigation on the life-history, habits, etc., of the insect, with a view to the possibility of evolving a suitable check on its ravages; and a general account of the progress made that season is incorporated in the second Report of Investigations on Flax

Diseases, published by the Department of Agriculture and Technical Instruction for Ireland (51)[1] in 1921.

The work was continued at Coleraine during the spring and summer of 1921, and in the present paper it is proposed to give an account of the life-history and habits of the beetle, together with detailed descriptions of the morphology of the different immature stages, and general information relating to the species in so far as it has been investigated up to the present.

The writer wishes here to acknowledge his indebtedness to Professor G. H. Carpenter, of the Royal College of Science, under whose guidance the work has been carried out, for much valuable help and criticism, especially with reference to the descriptions of the different stages.

2.—History and Synonymy of the Species.

The nomenclature of the flax flea-beetle has, unfortunately, been the subject of much controversy, and many descriptions under many different names have been published. Late workers, however, are agreed that the correct name of the species is *Longitarsus parvulus*—an agreement shared by the present writer.

From 1762, when Geoffroy (26) proposed for the flea-beetles the generic name *Altica*, until 1807, when Illiger (37) divided his genus *Haltica* into nine sections, and defined the characters common to each section, the position of the group was conjectural. Illiger gave to the seventh section the name "Longitarses"; and Latreille (46), in 1829, raised this section to generic rank. Two years later Stephens (59), in a new system of classification, founded the generic name *Thyamis*, and substituted it for *Longitarsus* Latr., while a further change was made in 1834 by Chevrolat (16), who, instead of employing either *Longitarsus* or *Thyamis*, used the new name *Teinodactyla*. *Longitarsus* is, therefore, the legitimate generic name.

The specific names *parvulus* and *ater* have been used simultaneously by various authors. Patterson (48), to whom the first record of damage to flax in Ireland by the species is due, uses the former, while several years later Janson refers specimens from Irish flax fields to the same species (61). After the publication of the catalogue of Gemminger and Harold (25), in which *ater* is given priority (from *Altica atra* F.), many writers adopted the latter specific name. Thus, it has been used by Bargagli (2) in Italy; Fowler (24), Sharp and Fowler (58), Hudson-Beare and Donisthorpe (36), and others in England; and Johnson and Halbert (39) and Carpenter (8) in Ireland.

[1] The numbers in brackets refer to the literature cited.

In 1775 Fabricius (19) described *Altica atra* thus:—"A. atra, nitida, antennarum basi plantisque piceis . . . . parva, tota atra, solis plantis pedum et basi antennarum subrufescentibus," with a reference to the *Altise 8* of Geoffroy (26). Twelve years later the same author (20), using a new system of classification, gives to *Chrysomela atra* a similar description; while in 1792 (21) he adopts the generic name *Galleruca*, and under *G. atra* is the description:—"G. saltatoria atra nitida antennarum basi pedibusque piceis . . . . parva tota atra solis pedibus piceis," with references to *Chrysomela atra* F. and *Altise 8* Geoff. Paykull in 1798 (50) further described a species as *Galeruca atra*, having *G. atra* F., and *Altise 8* Geoff. as synonyms.

In 1801 Fabricius (22) again altered the classification; substituted the name *Crioceris atra* for his *Galleruca atra*, and gave the latter, *G. atra* Payk., and *Altise 8* Geoff., as synonyms. In all Fabricius' works *atra* appears either immediately before or after *nemorum*—our present *Phyllotreta nemorum*.

Subsequent authors are not agreed that *Altica atra* F., *Chrysomela atra* F., *Galleruca atra* F., *Galeruca atra* Payk., and *Crioceris atra* F. are identical. Thus Gyllenhal (27) gives *Crioceris atra* F. as a synonym of *Haltica parvula* E. H.; Hoffmann et al. (33), Duftschmidt (18), and Redtenbacher (52) refer *Crioceris atra* F. to *Haltica atra*; while Olivier and Illiger (37) regard it as a synonym of their *Haltica atra*, which would appear to be different from the *H. atra* of other authors, inasmuch as it is placed by Illiger in his "Longitarses" division, being regarded by him as very like *H. anchusae* = *Longitarsus anchusae*. It may have been identical with that species. Foudras (23) and Allard (1) give *Galeruca atra* Payk., *Haltica atra* Ent. Hefte and Gyll. as synonyms of *Phyllotreta atra*, while Kutschera (44) gives *Galeruca atra* Payk. and *Phyllotreta atra* Foudras and Allard as synonyms of his *Haltica atra*. It is difficult, if not impossible, to refer definitely *Altica atra* F., *Galleruca atra* F., *Chrysomela atra* F., *Galeruca atra* Payk., and *Crioceris atra* F. to a present-day species; but from the references given it is concluded that they were our present *Phyllotreta atra*, so that the *ater* of Gemminger and Harold cannot be retained as the specific name of the species injurious to flax.

Paykull (49) in 1798 gave a description of a new species under the name *Galeruca parvula*. This description agrees precisely with the characters of the flax flea-beetle, and is that now generally regarded as the original; so *Longitarsus parvulus* Payk. is the legitimate name according to the present system of classification.

Hoffmann and his collaborators in 1803 (32) redescribed *Galeruca parvula* Payk. as *Haltica parvula*, with the former as the only synonym. Four years later Illiger (37) gave a further description under the name *Haltica pumila*,

with *H. parvula* Ent. Hefte and *Gal. parvula* Payk. as synonyms. Schönherr (57) gives many synonyms, but some of them can be referred to other present-day species. Thus, according to this author, *H. parvula* E. H., *Gal. parvula* Payk., *Crioceris atra* F., *Galleruca atra* F., *Altica atra* F., and *Chrysomela pulex* Schr. are identical.

Stephens (59), after the erection of his new genus *Thyamis*, described *Galeruca parvula* Payk. under the name *Th. parvula*, with *H. parvula* Ent. Hefte as the only synonym. After this the literature, especially British, contains many references to *Th. parvula* Steph. Thus, Curtis in 1837 (15) uses this name; Waterhouse in 1868 (62) sent the species thus named to Kutschera at Vienna, and the latter confirmed the determination; while Janson gave this name to flax-eating specimens from Ulster (61). Redtenbacher (52) was the first to adopt the combination *Longitarsus parvulus*, while Foudras (23), using the generic name *Teinodactyla* Chevr., with *parvula* for specific description, includes *H. parvula* Ent. Hefte, *H. pumila* Illig., *Th. parvula* Steph., and *L. parvulus* Redt. as the synonyms. Allard (1) in 1860 also uses *Teinodactyla parvula*; but here again *Chrysomela atra* F. is given as one of the synonyms. Two years later the binomial *L. parvulus* is again revived by Kutschera (44), with *Gal. parvula* Payk., *H. parvula* E. H., *Th. parvula* Steph., *Teinodactyla parvula* Foudr., and *H. pumila* Illig. as synonyms. In the latest European catalogue (31) *Longitarsus parvulus* is retained as the priority name, with *pumilus* Illig. and *ater* Leesb. as synonyms. Tomlin and Sharp in 1911 (60) also employ the specific name *parvulus*, while in the latest work on the species (1913) to which the writer has had access (28) a similar name is employed.

The synonymy of the species is therefore:—

Longitarsus parvulus (Payk.).

Galeruca parvula, .	Payk., Faun. Suec. ii (1798), p. 102. 22.	
Haltica parvula, .	Ent. Hefte, ii (1803), p. 59. 35.—Gyll., Ins. Suec. I, iii (1813), pp. 526–7.—Schönh., Synon. Ins. ii (1808), p. 312. 72.—Dftsch., Faun. Aust. iii, p. 268. 36.	
Haltica pumila, .	Illig., Mag. f. Insk. vi (1807), p. 170. 138.	
Galleruca atra, .	Fab., Mant. i, p. 78. 148.	Schönh., Synom. Ins. ii, (1808), p. 312. 72.
Crioceris atra, .	Fab., Sys. El. 1, p. 467. 88. Illig., Mag. i, p. 421. 88.	
Altica atra, . .	Fab., Sys. Ent., p. 115. 21.	
Chrysomela pulex, .	Schrank En. Ins., p. 85. 160.	

Crioceris atra, . Fab., Sys. El. 1, p. 467. 88.—Gyll., Ins. Suec. iii (1813), p. 526.—Allard, Ann. Soc. Ent. Fr. 3, viii (1860), p. 99.—Redtenb., Faun. Aust. (1858), p. 943.

Chrysomela atra, . Allard, Ann. Soc. Ent. Fr. 3, viii (1860), p. 99.

Thyamis parvula, . Steph., Illus. Br. Ent. iv (1831), p. 317.—Mn. 298, 2344.

Teindactyla parvula, Foud., Ann. Soc. Linn. Lyon, vi (1859), p. 258. 12.—Allard, Ann. Soc. Ent. Fr. 3, viii (1860), p. 99.

Longitarsus ater, . Gemm. and Harold, Cat. Col. xii (1876), p. 3502.—Bargagli, Bull. del. Soc Ent. Ital. x (1878), p. 73.—Sharp and Fowler, Cat. Br. Col. (1893), p. 30.—Johns. and Halb., Beetles of Ireland, Proc. R.I.A., 3, vi (1901), pp. 766-767.—Carpent. Econ. Proc. R.D.S., i, 3 (1902), p. 152.—Id., ii. 6 (1913), p. 83.—Leesb., Tijdschr., 25, p. 162.

Longitarsus parvulus, Redtenb., Faun. Aust. Ed. i, p. 535, ed. ii (1858), p. 943.—Bach. Kf. Fr. f. N. u. M., Stschl. iii., p. 149. 8.—Heyd., Reitter and Weise, Cat. Col. Eur. (1906), p. 578.—Schaum., Catal. Coleop. Eur. (1862), p. 113.—Tomlin and Sharp., Ent. M.M., 47 (1911), pp. 241-250.—Carpent., E. Proc. R.D.S., ii, 12 (1916), p. 226.—Kutsch., Wien. Ent. Monats. 7, vi (1862), pp. 223-4.—Heikert., In. Reitt. Faun. Germ. iv (1913), p. 198.

3.—Identification of the Species.

Longitarsus parvulus Payk. has long been familiar in the adult stage to Coleopterists in Ireland and Europe generally. Specimens bred at Coleraine and others received from Co. Cork were identified by Mr. J. N. Halbert, of the National Museum, Dublin; while on another occasion Mr. G. K. Blair, of the Natural History Museum, London, named specimens submitted for identification.

The other species of *Longitarsus* found in association with *parvulus* in Co. Derry were *luridus* Scop., *atricillus* Linn., *melanocephalus* De G., *suturalis* Marsh., and *jacobea* Waterh. Other species of flea-beetles, principally *Plectroscelis concinna* Marsh., *Phyllotreta nemorum* Linn., and *Sphaeroderma testacea* Panz., were also to be found on or near flax plots, but neither they nor the other species of *Longitarsus* could ever be seen attacking the seedlings.

The determinations of the above species were also made by Messrs. Halbert and Blair, to both of whom the writer acknowledges his indebtedness.

4.—Distribution.

Longitarsus parvulus appears to be widely distributed. The original description was made from specimens taken in Westrogothia (Sweden). Illiger (87) records it from the Rhine provinces, Portugal, and Sweden. According to Bargagli (2), it is common in the whole of Europe. Fowler (24) gives the British and Irish distribution thus:—"Very local; London district, rare, Chatham, Dulwich; Whitstable; Birchington; Deal; Ditchingham, near Bungay, Suffolk, abundant (Power); Ashwicken and Wicken Fen; Markfield, Leicester; Portsmouth district; Seaton Down, Devon; Ireland, Rathkurby, near Waterford (Power); Belfast (Haliday) and Armagh (Johnson)." Johnson and Halbert (39) give the distribution in Ireland as follows:—Donegal and Derry: Foyle district; Antrim: Ballycastle, Lisburn; Down: near Belfast; Armagh: Poyntzpass; Cavan: Ballyhaise; Waterford.

It is thus seen that the known range of the species in Ireland was at that time (1901) confined to the province of Ulster, with a single record from Munster. In the meantime, further records have been obtained from these two provinces, but as yet no specimens of the species would appear to have been taken in Leinster or Connaught. This may be due to the non-occurrence of the species as a pest, or, perhaps, to the absence of collectors, since it is readily conceivable that if flax were to be grown in north-west Co. Louth, it would be attacked like that grown in south Co. Armagh and south-west Co. Down. Of late years the species has become so prevalent in the flax-growing districts of Co. Cork as to constitute a serious pest, although Johnson and Halbert give no record from that county. In September, 1921, the writer took an opportunity of visiting a flax-growing district in Leinster (Co. Wexford), and made a search for flax-beetles, but without success.

5.—Description and Habits of the Adult.

The adult has been studied by many systematic workers on the Coleoptera, and representative descriptions are given in various publications (24) (60); hence a detailed description is not considered necessary here. An enlarged drawing of the adult is, however, shown in the figure A.

Except immediately prior to egg-laying, the sexes can hardly be distinguished at sight. The gravid females are, however, quite distinct from the males, as the abdomen is distended ventrally and posteriorly, so that the elytra do not completely cover it, but appear somewhat convex. Moreover,

the tergites and sternites of the abdominal segments are pushed apart, so that they appear as black bands in the yellow intersegmental cuticle. The aedeagus of the male, as shown in the text figure B, is a conspicuous, elongated, and strongly chitinized organ, which normally remains retracted into the abdomen. Slight pressure will, however, cause its protrusion, and then the sex can be determined.

Fig. A.
Longitarsus parvulus.
Adult. × 26.

Fig. B.
Aedeagus of Male.
× 86.

The beetles are most active, and are seen in greatest numbers during sunny weather, especially during bright sun after showers of rain. In wet weather they are not noticeable, as they are then in the soil, sheltering beneath little lumps of earth. But when the rain ceases and sunshine supervenes, they come up and rest on dry stones in the soil, or even on lumps of soil, prior to ascending the food plant. When the top of the plant is reached, suitable leaves are selected, and feeding commences. Thus the youngest foliage is always selected for food, and rarely does one find a beetle feeding on foliage low down on the plant. The beetles appear to favour the thinner parts of a braird, and to eat the seedlings on such parts in patches, so that thin, uneven brairds of weakly seedlings are most liable to be attacked. Flight is common in spring, when the adults leave their winter quarters to go to fields of flax, and again towards the end of the season, when the crop has been pulled. During the active feeding period flight rarely occurs, as the beetles

move about chiefly by jumping, although walking with the ungainly gait characteristic of flea-beetles is also common.

The adults of this species possess extraordinary jumping powers, and are extremely difficult to catch during warm weather in May and early June. They are much more active than the related turnip flea-beetle, and more sensitive to approaching disturbances. This activity wanes as July approaches, as by that time the life of these adults is practically at an end. When not feeding, the beetles often shelter underneath the leaves of flax plants, where they are hidden from the casual observer.

6.—Occurrence as a Pest.

The first mention of the species from the economic point of view appears to have been made by Patterson, of Belfast (48), who thus describes its ravages: "As linen is the staple manufacture of this part of the country, and gives employment in various departments to many thousand persons, the flax crop is naturally regarded as one of very high importance; yet here a diminutive insect had the hardihood to interfere, and, despite of all the efforts of man, nearly destroyed in many parts of the Co. Down, in the summer of 1827, the entire crop of flax. The minute assailant was a little jumping beetle (*Haltica parvula*), resembling that called the turnip-fly, but much smaller."

The next record of damage is found in the *Transactions* of the Entomological Society of London for the year 1869 (61), and is to the effect that the Secretary of the Society "read a letter from the Secretary of the Flax Improvement Association of Belfast, respecting the damage done by a small beetle to the flax crop, especially whilst the plant was in the seed leaf. The species was determined by Mr. Janson to be the *Thyamis parvula* of Paykull."

Under the name *Longitarsus ater* Fab., Carpenter (8) records an attack near Lisburn in June, 1901, and mentions that the insects had eaten nicks and holes in the young, tender leaves. This is presumably the same attack that is referred to in the *Journal* of the Department of Agriculture and Technical Instruction for Ireland, 1901 (40), in a report on a sample of flax plants sent from Lisburn which were found to be attacked by *Longitarsus ater* Fab., and "holes and nicks had been eaten out of the leaves of the opening leaf-buds." Further ravages of this pest are recorded by Carpenter in his report for the year 1912 (9). During that season the beetles appear to have been very numerous and destructive, some fields having the brairds completely eaten in patches, and not a single plant left; whilst in parts of Co. Antrim the crop had to be resown. A further report by Carpenter (10) is to the

effect that "in June, 1915, it was particularly abundant and destructive in Ulster"; and in his latest report (11) he mentions that "this destructive little beetle caused much damage to the flax crop in all three seasons under review"—1916, 1917, and 1918—and that "in 1917 and 1918 it was found necessary to resow the crop in several localities." It has been estimated that in the year 1917 fully 30 per cent. of the early sown flax in Co. Down was destroyed by flax flea-beetle attacks.

In the reports of the manurial experiments on flax carried out by the Department of Agriculture, two instances of insect attack are mentioned which, although obscure, may with tolerable certainty be referred to the flax flea-beetle. In the report of the 1909 season experiments (41), when referring to factors affecting the growth of the crop, a statement is made to the effect that "at Ballindrait the brairds were badly eaten by grub"; and the report for season 1913 (42) states that at Newmills centre, "after the brairds suffered injury from an insect attack, the crop grew so irregularly as to render necessary the abandonment of the trials." The latter is obviously a reference to flea-beetle injury; but, in the first case, the damage may have been caused by "leather-jacket" grubs (*Tipula* sp.). During the season of 1919 severe attacks were reported from the flax-growing districts of Co. Cork, and in Ulster the species was abundant, and did appreciable damage.

The season of 1921 was remarkable because of the long drought—a condition often suggested as most favourable to the ravages of flea-beetles—yet during that season the flax brairds of the different districts in Ireland where the crop is grown were singularly free from attack, and few reports of serious damage have been recorded.

From Ballinacurra, Co. Cork, a complaint was received that some early sown plots of flax at the Department's plant-breeding station there were being injured by insects, and on examination of the specimens forwarded the species was identified as *Longitarsus parvulus* Payk. The attack was, however, local and chiefly confined to very early sown plots. A similar condition prevailed at the experimental plots in connexion with the field laboratory in Co. Derry. A series of plots sown early in April, and brairding during the last week of that month, were extensively infested, and the young plants suffered considerably. The remainder of the plots were sown during the first week of May, and, brairding twelve days later, were not so attacked, and suffered little appreciable injury, although beetles were present in small numbers, having migrated thence from the earlier sown plots. During the brairding of the flax on the latter the beetles were observed flying to them from all directions; and it is possible that, as this was the only flax brairding in the immediate district, the beetles swarmed on it as

the favoured food plant, attracted thereto by tropisms as yet unexplained. Apart from these slight attacks—both of which occurred on early sown flax—the brairds of 1921 suffered little, if at all, from flax flea-beetle depredations. Some probable factors in the origin of this freedom from attack are discussed in section 9.

Outside of Ireland there are few, if any, authentic records of damage to flax by this species. Heikertinger (28) records *parvulus* as the only species of the genus *Longitarsus* known to injure flax; but there is nothing to indicate that the injury referred to occurred in Germany. More recently, Blunck (3) includes *L. parvulus* Payk. in his list of the insect and other animal enemies of flax; but here again the country is not specified. Kuhnert (43) does not make any mention of *L. parvulus*, but records *Phyllotreta nemorum*, our turnip flea-beetle, as destructive to flax seedlings.

7.—Range of Food Plants.

Cultivated flax, *Linum usitatissimum* L. is, undoubtedly, the favoured food plant, and is eaten in preference to all others, with the possible exception of narrow-leaved flax, *Linum angustifolium* (Huds.). The latter is a dwarf spreading species, found growing wild in the south and east of Ireland, but not in the north. A small plot grown from seed at Coleraine in 1920 became badly infested with beetles, and was eaten simultaneously with cultivated flax growing alongside. The preference for flax is well seen in spring if a small plot be sown early. The beetles, if the weather be suitable, will gather to it rapidly and feed voraciously, showing no desire for other plants. Purging flax, *Linum catharticum* L., is eaten if supplied to beetles in captivity; no definite proof, however, of its having been eaten in the open could be seen.

Other alternative food plants are clovers and grasses. These have been observed to be eaten both in the field and in laboratory cages; but in the open are only attacked late in the year after the flax has been pulled, and possibly in spring, if there is a spell of dry warm weather before the flax brairds are ready. Twenty beetles lived happily on a plant of white clover (*Trifolium repens*) in one of the laboratory cages. The leaflets were not notched or perforated, but were eaten from the under surface, usually near the insertion of their stalks, the upper epidermis being left intact. In the field, however, leaflets with notches eaten out have been observed late in the season. Of the grasses, the younger leaves seem to be preferred.

Some experiments were made to determine if the beetles showed a preference for any of the common weeds when flax is not available.

Seedlings of various weeds were raised in pots, and a number of adults caged on each species of weed, no other food being supplied. The following weeds were used:—Spurrey (*Spergula arvensis*), Daisy (*Bellis perennis*), Dock (*Rumex* sp.), cut-leaved Geranium (*Geranium dissectum*), Goosefoot (*Chenopodium album*), Charlock (*Sinapis arvensis*), and Redshank (*Polygonum Persicaria*). In all cases the seedlings remained free from attack, the beetles showing no attempt to feed on them. In the field, observations were made to detect, if possible, weeds eaten by the beetles, but no definite instance of such could be seen.

Records of food plants in the writings of other workers are singularly rare, and, beyond these from flax in Ireland, there is little definite information to be found. Allard, according to Fowler and other writers, states it is commonly found on the Hornbeam (*Carpinus Betulus*) in woods; but that it actually feeds thereon is doubted by some authorities. The present writer has not had an opportunity of making observations regarding this possible food plant. "On low plants" is the general habitat given by Fowler (24), whilst the original description gives the "habitat in pratis ad fossas in Westrogothia Dom. Gyllenhal" (49), but mentions no food plant.

8.—Nature of Damage.

(*a*) *By the Adult.*—The principal damage is caused to the flax in its seedling stage, and by the adult insect. The cotyledons of the seedlings are the parts first attacked, with the result that they become perforated and notched, as shown in Pl. XV, figs. 1, 2, 3. If the attack is severe, the entire cotyledons and the terminal bud between them may be devoured, in which case the seedling succumbs.

When this is not the case, and when the terminal bud proceeds to give rise to young foliage leaves, the beetles leave the cotyledons and begin to devour these tender leaves. Even at this stage the severity of attack may increase, so that the young plant becomes entirely destroyed.

It frequently happens, however, that the attacked seedling goes on growing and ultimately produces a plant. Nevertheless, the injury done to the terminal bud of the seedling induces the development of lateral buds in the axils of the foliage leaves which would otherwise remain dormant, hence flax plants which in their early days have been attacked by the flea-beetle are frequently branched, but such induced branching must not be confused with the normal branching which is found in some strains of cultivated flax.

It is noticeable that the beetles always prefer the newly developed foliage leaves; and at a given time they are nearly all to be found in relatively the

same regions of the plants, the most favoured one being between two of the newly developed leaves just behind the growing point. The effects of the feeding beetles become less obvious as the plants increase in size, and little anxiety is felt regarding damage. The newly emerged adults in August attack old flax stalks, and have been observed to "bark" them completely in the attempt to secure sufficient preferred food.

(*b*) *By the Larva.*—The feeding larvae live on the flax roots, tunnelling into and feeding upon their soft parenchymatous tissues. The youngest parts of the roots seem to be preferred. Whilst plants growing in restricted amounts of soil in pots in laboratory cages suffered as a result of the larvae feeding upon their roots, no damage which could be ascribed to the activities of feeding larvae was observed in seedlings growing in field cages, or in plots in the open field. This is probably due to the fact that about three weeks must elapse from the time the eggs are laid until the larvae are capable of doing appreciable damage, and during this time the flax plants will have formed an extensive root system, and thereby become proof against serious injury. The fact, however, must not be overlooked, that where the growth of seedlings has been delayed, owing to unsuitable conditions, or otherwise, the inherent possibility of these larvae feeding in the roots, and thus further retarding growth, always remains.

It is interesting to note that in the case of the larvae of the Chrysomelid genus *Donacia*, which live upon the roots and stems of aquatic plants, Böving (4) concludes that the plants rarely suffer from the effects of the feeding larvae. Howard (35), referring to the larvae of the tobacco flea-beetle (*Epitrix parvula F.*), which feed upon the roots of the tobacco plant, is of opinion that "the damage done to the roots . . . must affect the health of the plant to a certain extent, but it is not appreciable in comparison with the damage which the adult beetles do to the leaves." Chittenden and Marsh (14) state that the injury done to cruciferous plants by the root-feeding larvae of the Western Cabbage Flea-beetle (*Phyllotreta pusilla* Horn.) is negligible, but the larvae of the Desert Corn Flea-beetle (*Chaetocnema ectypa* Horn.) are, according to Wildermuth (63), highly destructive to alfalfa and maize by reason of the damage done to the roots on which they feed.

9.—Conditions which Favour Attacks.

The opinion is generally held by farmers that attacks by flea-beetles are largely governed by the time of sowing, tilth of soil in the seed-bed, and the prevailing weather conditions at and for weeks after brairding—all factors which tend to exert considerable influence on the rate of growth. Thus,

given dry, warm weather in May, after weather not conducive to the thorough cultivation of the seed-bed, the prospect of a bad attack becomes highly probable, inasmuch as such conditions retard the growth of the seedlings at a time when, stimulated by the prevailing warmth, the adult beetles are encouraged to come out of hibernation; whereas if the weather remains cold, although growth may be seriously checked, the beetles are not encouraged to activity, and therefore the seedlings escape their attentions. When, however, conditions conducive to vigorous growth are secured, the dangers of serious results from attack are minimized, because the seedlings are enabled by rapid growth to overcome the possible effects.

Early sown fields often suffer considerably greater damage than those sown some days later. This was very apparent in Co. Down about four seasons ago, when many growers had the brairds on the early sown fields completely destroyed, although later sown fields suffered much less, and the latest ones were not appreciably damaged. The reason for this is not yet clear, but, as already pointed out, the beetles gather in, probably attracted by a scent stimulus, from surrounding hibernating places to a field in which flax is brairding. Since brairding flax is not common at this early period, it is highly probable that all the beetles which have hibernated in that particular district will come to the young seedlings. Moreover, the beetles have a greater capacity for food after coming out of hibernation, and prior to egg-laying, than at a later period, so that a field of early sown flax is attacked by a much greater number of beetles which, individually, possess the maximum capacity for food.

The idea that warm, dry weather favours a bad attack only holds provided the beetles are actually present to cause the injury. Thus, the season of 1921 was an ideal one as regards suitable weather for flea-beetle depredations; nevertheless, as already stated, there was an uncommonly slight infestation throughout the different districts. From the study of the life-history and observations thereon, the writer is of opinion that the prevailing weather during May and June, i.e., the months during which the earlier stages are passed, determines to a large extent the infestation of the *following* spring; because it is the beetles which emerge during late July and August as a result of eggs laid in May that are, after the hibernation period, responsible for the damage which may be caused during the following season. Therefore, if the weather during the months of May and June is fine, dry, and otherwise conducive to the health and safety of the minute and delicate larvae in the soil, the number of adults ready to attack flax seedlings the following spring will be correspondingly large. Moreover, if warm, sunny weather prevails during late April and early May, the females

are induced to oviposit early, and a correspondingly early emergence of a brood of adults will result.

This early emergence further helps in the multiplication of the species, because it is completed before the pulling of the flax crop begins, and the soft, delicate pupae in the soil will thereby escape possible injury and destruction during the process. The weather during the hibernating period and the convenient presence of suitable and reliable winter quarters are also factors which undoubtedly influence to a large extent ultimate infestation.

The season of 1920 was particularly wet and cold, with little sun during the early part of May. Egg-laying was consequently delayed, and the emergence of the resulting brood of adults had only commenced when the pulling of the flax crop started. The pupae were present in the soil in considerable numbers, and no doubt many were destroyed, and others injured sufficiently to prevent emergence of the adults. The mortality would be further increased by the subsequent operations, such as carting, and further by stock grazing on the fields after the flax had been removed.

Besides these checks on emergence, the wet, cold soil must have caused a comparatively high death-rate amongst the newly hatched larvae, as actually occurred in the rearing experiments conducted in laboratory cages, when the soil in which the supporting seedlings were grown was watered to excess.

These adverse conditions may, therefore, have been responsible for the singular freedom from attack last season (1921), and, if so, we may anticipate bad infestations during seasons following a dry and warm spring and summer. In this connexion it is interesting to note that Carpenter, when recording the unusually destructive attacks of May, 1912, states that such were "probably as a result of the hot and dry summer of 1911" (9).

10.—Descriptions of the Immature Stages.

(*a*) *The Egg* (Pl. XVI, fig. 6). — Elongate, oval in shape, cylindrical, with rounded ends; where two or more are pressed together in a cluster, the sides sustaining the pressure are sometimes flattened. The chorion is tough, and under high magnification is seen to be covered with numerous depressions, which are bounded by more or less straight five-, six-, or seven-sided walls, the raised areas between the depressions giving to the surface a distinct and characteristic network appearance (Pl. XVI, fig. 7). After oviposition, the colour is pale yellow, and the surface appears shining and translucent; during hatching the colour changes to yellow-brown or orange, and the surface becomes opaque and dull. Eggs which have been deposited for eight or nine days show up in fairly striking contrast to the soil in which they are deposited.

The average length is 0·59 mm. and the average greatest breadth 0·23 mm. The size is, however, not uniform, as the following measurements of eggs from different clusters show :—

Length (mm.)	Greatest Breadth (mm.)
0·55	0·17
0·61	0·23
0·61	0·28
0·64	0·29
0·55	0·20
0·58	0·21

(*b*) *The fully grown Larva* (Pl. XVII, fig. 23).—The details of the larval descriptions which follow are from fully grown specimens, and to avoid repetition the description of the fully grown larva is placed before those of the earlier stages.

The length varies from 3·6 mm. to 4·5 mm., according to the time that had elapsed since the previous moult. Form narrowly elongate, nearly cylindrical, the sides more or less parallel from the posterior margin of the prothorax to the posterior margin of the eighth abdominal segment, the average diameter being 0·40 mm. Colour opaque white, excepting for the head and the posterior end of the abdomen (ninth abdominal tergum), which are firmly chitinised and of a dark orange-yellow colour. The cuticle otherwise is soft throughout, and bears numerous brown coloured bristles on indistinct tubercles, which are placed on the body in a regular order.

(i) *Head* (Pl. XVIII, figs. 25, 26, 27).—This consists of a strongly chitinised capsule, which completely envelops the dorsal and lateral regions. Ventrally, the head is feebly chitinised and white in colour. The chitinous part is dark yellow or orange, and when viewed from above with a low-power binocular is seen to be divided into two distinct parts by a narrow dark ridge, which extends along the median line. The capsule is strongly arched towards the posterior margin, and the latter is hollowed out into a deep V-shaped groove. From the centre of the groove the epicranial suture (*epsu*) extends anteriorly, and appears as a light-coloured narrow space for a short distance along the median line. It then divides to form the two frontal sutures (*frs.*), which extend obliquely forward and outward to become obsolete a short distance from the margin of the frons at the insertion of the antennae. These sutures also appear as clear lines in the chitinous capsule, and together form a well-defined V, enclosing the portion of the head known as the frons. The frons (*fr.*) is divided into two by the dark brown or black

line already referred to, which extends from the junction of the epicranial and frontal sutures along the median line to the epistome. This is the frontal ridge (*frr.*), and is obviously a strengthening band of chitin. The dorsal surface of the head is therefore divided into three distinct areas :—the epicranial region (*epc.*) at each side, and the frons. The epicranium extends ventrally to the fleshy stipes of the maxilla, and supports the antenna laterally and towards the anterior margin.

The frons is sub-triangular, and has along its anterior margin a very strongly chitinised narrow region—the epistome. The latter is emarginate anteriorly for the clypeus (*cl.*), and extends laterally to the pleurostome (*pls.*), which provides, on its anterior margin, articulatory surfaces for the condyles of the mandibles. The clypeus is a narrow transverse band, extending between the epistome and the labrum. It is little chitinised, and pale yellow in cleared preparations. Anteriorly it is emarginate for the labrum, the posterior margin of which is situated ventral to the clypeus, so that normally the articulation for the labrum is along the ventral surface of the anterior margin (Pl. XVIII, fig. 34). The ventral surface of the head (Pl. XVIII, fig. 25) shows the fleshy protruding maxillae, between which is the globular submentum (*sm.*) of the labium. Posterior to the submentum is a membranous region, little chitinised, which corresponds to the gula (*gu.*). Between it and the prothorax there is no distinct suture, and it may therefore be regarded as an anterior extension of the prothorax.

The maxillary and labial palps project antero-ventrally, and the mandibles cross beneath the labrum, so that normally none of the mouth-parts except the labrum is visible in dorsal view.

The study of the arrangement of the bristles (setae of many writers) on the head-capsule is important, for, as already pointed out by workers on Lepidopterous larvae, they may prove to be highly useful in the differentiation of closely allied species (29). Generally speaking, the head bristles on *L. parvulus* larvae are in transverse rows, somewhat similar to those on the body, to be described later. Each lateral region of the epicranium carries on the dorsum two pairs of strong bristles, one pair being beside the frontal suture and the other towards the lateral margin. Slightly anterior to, and medianly from, the latter pair of bristles a round clear spot, resembling the follicle of a bristle, occurs in the chitin. Following Heinrich (29), such spots are called punctures. Towards the posterior angles of the epicranium there occurs at each side a series of five such punctures, in which very minute bristles may sometimes be seen. These occupy a somewhat similar position on the head to the ultra-posterior punctures (secondary punctures of Heinrich) described for various species of Lepidopterous larvae (7), (30),

(34). Midway between the two large bristles, which occur near the frontal suture at each side, there is a minute puncture, which sometimes carries a more minute bristle. Just ventral to the lateral margin of the epicranium another strong bristle occurs, and antero-ventral to it is a puncture. Ventral to the antenna there is anteriorly and near the pleurostomal margin a strong bristle, whilst a small one arises ventral to and near the posterior extremity of the insertion of the first antennal segment.

The frons carries a transverse row of four long, strong bristles, which arise just on the posterior margin of the epistome. Posteriorly, and in the order given, there are present also on the frons two small bristles (one at each side of the frontal ridge), two punctures, and, well back towards the epicranial suture, two further punctures.

The close similarity between this arrangement of bristles and punctures and that commonly found on the head capsule of Lepidopterous larvae is very apparent, and is here referred to because of the interest which such similarity affords from the phylogenic point of view.

The clypeus is provided with a transverse row of what appear to be bristle-follicles or punctures, but close examination reveals very minute bristles in them (Pl. XVIII, fig. 35). The number does not appear to be constant; four at each side is the usual condition, although an additional one is often present at either side.

The antennae (Pl. XVIII, fig. 28) are situated on the lateral margins of the epicranium, and just posterior to the pleurostome. Each consists of three segments,[1] the basal one being large, flattened, and in close contact with the head. The middle segment is smaller, more cylindrical, and is provided with a number of sensory structures towards the apex. These consist of:—a long, blunt, prominent process, which arises on the inside of the segment, and projects inwards and forwards; three short and blunt spines, which arise from rounded pits; and one or two similar pits devoid of such spines. All these structures are on the dorsal aspect of the segment. The terminal segment is sub-conical, inclined to be somewhat pear-shaped, and is not provided with any sensory appendages.

Ocelli are absent.

(ii) *Mouth parts.*—The labrum (Pl. XVIII, fig. 34) is light yellow in cleared preparations, and somewhat triangular in shape. The free margin is distinctly tripartite and arched dorso-ventrally. Each outer lobe carries five strong blunt bristles, which arise from the ventral surface near the margin, and curve inwards towards the centre, while the middle lobe is provided

[1] Some writers regard the flat basal segment as a projection from the head. In this paper it is considered a distinct segment.

with two series of short, straight projections, also from the ventral surface of the margin. Dorsally there is a transverse row of four long bristles, one from each of the lateral angles being much longer than the median pair. Between the latter there are two round and comparatively large punctures.

The epipharynx (Pl. XVIII, fig. 36) is closely attached to the ventral surface of the labrum, and often difficult to define. It would appear to be a membranous structure, having a series of four short, blunt projections at each side of a somewhat triangular concave area.

The mandible (Pl. XVIII, figs. 29 and 30) is strong, firmly chitinised, dark brown or black, prominently situated ventral to the labrum. The base is roughly triangular in section, and the apex is divided into five strong blunt teeth. From the ventral posterior angle a prominent condyle arises, which articulates with the head capsule by means of an acetabulum formed in the ventral anterior angle of the pleurostome. Dorsal to the condyle is the insertion of the abductor muscle, whilst the much stronger adductor is attached to the inner surface of the dorsal posterior angle.

The mandible is strongly arched, and carries on the outside towards the posterior margin two small bristles. The molar region is provided with two sharp, stout spines, which project inwards towards the buccal cavity. The anterior spine is larger and distinctly curved.

The maxilla (Pl. XVIII, figs. 31, 33) is prominent by reason of the fleshy stipes and projecting palps. It consists of galea (*gal.*) and lacinia (*lac.*) imperfectly divided; palp (*mp.*), supported by a large palpifer (*pfm.*); large stipes (*st.*); and small basal cardo (*c.*). The cardo is soft and little chitinised, roughly rectangular, and has a process for articulation with the head at the outside basal angle. It bears a single minute bristle towards the lateral margin and posterior to the cardo-stipes joint. The stipes is strengthened by a pronounced band of chitin, which extends anteriorly to encircle the lacinial region on the inside. It carries one large and one small bristle, between which is a single puncture. The galea is rounded and strengthened by a chitinous band, which encircles the apex. The latter carries a number of short, blunt spines, and one larger, two-segmented spine.

On the ventral surface of the galea and slightly below the apex three minute bristles occur, the innermost being longest, and placed on or near the lacinial region. The lacinia cannot be separated from the galea. It consists of a narrow band of tissue, from which there arise on the ventral face and near the apex five long, slender bristles. These project inwards, and normally are in close contact with the hypopharynx. The palpifer is a stout structure, strengthened by an enveloping band of chitin. It carries two small bristles on the ventral surface, and has one round puncture just dorsal to the lateral

margin. Exhibiting all the characters of a palp segment, it supports the three-segmented maxillary palp. The basal segment of the latter is narrow, strengthened by an enveloping band of chitin, and has on the inside (dorsal) face one small bristle and two punctures. The second segment is similarly strengthened, and has one small bristle on each of the dorsal and ventral faces, and a couple of punctures dorsally. The terminal segment is subconical, not chitinised, and does not carry any bristles.

Labium (Pl. XVIII, figs. 25 and 37).—This can easily be recognized by the two short palps (*lp.*), which project ventrally and slightly forward. These are simple, unsegmented structures, without any sensory appendages. They arise from short, flat, ring-shaped palpifers (*pfl.*), which are supported on a broad, rounded basal piece—the mentum (*me.*). Besides the palps, the mentum carries a pair of long bristles, which are placed near the posterior margin. It is supported by the globular and fleshy submentum (*sm.*), which extends posteriorly to occupy the middle position as far as the gula. It has two pairs of bristles, which arise near the lateral margins; one bristle at each side is anterior, and the other is situated near the posterior angle at each side.

Anterior to the mentum and intimately fused with it is a well-defined area provided with a number of minute but distinct structures. This is the remarkably modified ligula (*lig.*) or fused labial laciniae and galeae. The structures which it bears are obviously sensory organs, and no doubt are equivalent to the spines and bristles already described as occurring on the apices of the maxillary laciniae and galeae. There are five of these organs at each side of the middle line of the ligula. The two nearest the anterior margin have strongly chitinised bases, from which project pointed spines. Posterior to these are two pairs; the inner pair resemble minute cylinders, and are not provided with observable projecting spines, but the other (outer) pair have pointed processes arising from circular pits. The next pair resemble those last described, and the posterior pair are similar to those described as the inner pair of the second anterior row. In young larvae the bristles of these structures are usually longer than in fully grown larvae, while occasionally an extra organ is present at one side or the other. Fig 13, Pl. XVIII, shows the general arrangement of these structures and of the other parts of the labium. The tip of the hypopharynx is seen projecting beyond the ligula.

Hypopharynx (Pl. XVIII, figs. 32 and 37).—This is closely attached to the labium. In preparations of the complete head it is seen as a rounded prominence, occupying the greater part of the region between the mandibles immediately ventral to the opening into the buccal cavity. Under

a very high-power magnification this portion is seen to be provided with numerous slightly elevated papillae, from which there arise very minute hairs. No doubt, these are taste organs, and possibly sensory with regard to touch. These papillae extend inwardly on the dorsal face, and are present on two somewhat raised lateral areas or lobes, where, moreover, their hairs are longer. From their position and structure these lobes may represent maxillulae, which have already been described as occurring in many species of coleopterous larvae. A chitinous band extends at each side of the hypopharynx, and posteriorly forms a point of attachment for muscles for the movement of that organ.

(iii) *Thorax* (Pl. XVI, figs. 12 and 13).—The prothorax is the smallest segment, the mesothorax larger, and the metathorax largest. The pronotal shield is not strongly chitinised, and not distinct, undivided dorsally, but prescutal and scuto-scutellar areas indicated by two transverse rows of bristles; the shield has a distinct mid-dorsal suture, on each side of which three bristles occur in each of the two transverse rows. One row is placed just anterior to the posterior margin of the pronotum, while the second series of bristles arises towards the front margin. The last bristle in each series occupies a position on the raised lateral margin, which corresponds to the alar lobe.[1] This area further carries another small bristle which arises in front of the anterior series. Ventral to the alar lobe and towards the front margin a single bristle occurs on a small pigmented plate in the cuticle.

The mesothoracic and metathoracic tergites are divided into two distinct areas, the anterior one representing the prescutum and the posterior the scuto-scutellum. The mesothorax, when a cleared and stained larval cuticle is examined, shows many and variously shaped, granular-structural plates, from which arise the brown tipped bristles. These areas are present in a certain definite order on all the segments of the body, but in the case of the pronotum and ninth abdominal tergum fusion has taken place in the modification of these parts for particular purposes. They are analogous to the oftentimes very prominent and pigmented areas present on the segments of larvae of many other Chrysomelidae, e.g. *Phyllotreta nemorum*.

In *L. parvulus* larvae they are not conspicuous when living specimens are examined; in fact, if the larva has recently moulted, they are often difficult of determination, even in cleared and stained preparations. Those occurring laterally, however, appear (especially in young specimens) as prominent lobes on the pleural region of the abdominal segments one to eight. The

[1] The terminology used is adapted from Böving and Champlain: Larvae of North American Beetles of the family Cleridae. Proc. U. S. Nat. Mus., 57 (1920), pp. 575-649.

bristle-bearing areas or plates occurring on the metathorax area: a narrow, transversely elongated plate having a median longitudinal suture and provided with a single bristle at each side, on the prescutum; lateral to this plate is a small triangular-shaped one devoid of bristles; the united scuto-scutellum has dorsally a plate similar in construction and armature to that of the prescutum, while lateral to it at each side a single bristle-bearing triangular-shaped plate occurs; ventral to this and extending longitudinally across the segment is a large crescent-shaped plate, with one large bristle at the posterior end, a larger bristle medianly, and two minute bristles anteriorly. This plate occurs on the alar lobe, and the bristles on it may be referred to as the alar bristles. Ventral to the alar lobe, towards the posterior margin, is a small plate bearing a single bristle. From the position of the spiracle this may be regarded as the homologue of the plate occurring on the epipleural lobe of the abdominal segments, and its bristle is therefore the epipleural bristle of the mesothorax. Anterior to this is the plate in which the spiracle opens. It is roughly triangular in shape, and the anterior angle carries a small bristle.

On the metathorax the arrangement of the bristle-bearing plates and bristles is exactly similar. Here, however, the alar-lobe plate is larger, and the spiracular plate has not a visible spiracle, thus differing from other Chrysomelid larvae, e.g. *Donaciae,* inasmuch as the latter, according to Böving, possess on the metathorax a pair of "small, impenetrable, and useless spiracles (5).

The legs are placed latero-ventrally towards the posterior margin of the segments on prominent coxal (hypopleural) lobes. The thoracic sternites are imperfectly divided, and the different areas difficult of determination. The sternum of the prothorax has two large plates fused at the middle line and provided with one pair of fairly large bristles near the median line and towards the post-sternellum. The meso-sternum carries a pair of large fused plates anteriorly. These bear a single pair of bristles, and, towards the posterior angles, a pair of minute punctures. The post-sternellar region has a small triangular plate at each side of the median line provided with a single minute bristle. The meta-sternum is similarly strengthened and armed, but the anterior plates are usually smaller.

(iv) *Legs* (Pl. XVII, figs. 16 and 19).—These are all about equal in size, short and stout. They appear to be composed of segments homologous with the coxa, trochanter, femur, tibia, and tarsus of the adult. The coxa articulates with a large flattened, chitinised acetabulum, which is supported by the coxal lobe. Anteriorly the acetabulum is strengthened by a thick band of chitin, which passes laterally as a ridge. This is armed with usually two, but

sometimes three, long, stout bristles, while a number of smaller bristles occur on other regions of the acetabulum, as is seen from the drawings. The acetabulum, or chitinised part thereof, appears to be analogous to Sanderson's tubercle IX (56), which was considered by him to be the same as the "trochantin" described by a previous worker. The coxa is fairly large and fleshy, but not well seen from the inside, as it is obscured by the trochanter, a triangular piece which extends on the inside of the leg towards the acetabulum. At the outside the trochanter is narrow and not armed, but from the inside face one very long and a few short bristles arise. The femur is rectangular in profile, and comes off from the trochanter at an angle. It also carries on the inside one very long bristle, and towards the front a few short, stout bristles. The tibia is elongate-narrow, and is armed with many short, stumpy bristles. The tarsus is very small, and is best seen in inside view. It is closely approximated with a single, strongly chitinized, backwardly curved claw. A small bristle occurs on the inner surface near the apex. External to each claw there occurs a large, rounded bladder-like tunica (pulvillus of some writers). This shows, under a high-power magnification, a series of longitudinal wrinkles or folds, which suggest capabilities for expansion if necessary. It is obviously an organ for facilitating locomotion, and appears to be general in the larvae of flea-beetles. Carpenter[1] has described it as occurring in the larva of *Psylliodes chrysocephala* L. (12). The writer finds a similar structure well developed in the larvae of the genus *Phyllotreta*; while Sanderson (56) gives it as a specific character in the classification of Chrysomelid larvae. The similarity between this arrangement of larval foot-structures and that found in the members of the Collembola genus *Sminthurus*, as pointed out by Carpenter (12), is highly interesting in view of the recent proposal to regard the Chrysomelidae and other families of Coleoptera having specialized larvae as being primitive types (45).

(v) *The Abdomen.*—This is composed of ten segments, of which the first eight are similar regarding armature and general structure. The first is the smallest, and the eighth often the largest. Each tergum of segments one to eight is dorsally divided by transverse depressions into three distinct areas—prescutum anteriorly, scutum medianly, and scutellum posteriorly. The scutum is always the smallest of the three regions, and is very narrow on the first abdominal tergite. The prescutum bears dorsally a single transversely elongated plate, which extends unsutured across the median line, and is provided with two bristles. Lateral to this at each side, and horizontally

[1] With reference to the position of the tunica, the word "internally" occurring in the paper referred to is an error. The tunica is external in *Psylliodes*, as in *Longitarsus* and *Phyllotreta*.

opposite the alar and epipleural lobes respectively, are two smaller plates, each with a single bristle. There is therefore a transverse series of six prescutal bristles on each abdominal segment one to eight. The scutum is provided with a rounded, single bristle-carrying plate at each side of the middle line, thus giving a transverse series of two scutal bristles. The scutellum is the largest of the segment divisions, and bears dorsally a fused plate with two bristles extending equally to each side of the median dorsal line, similar to that on the prescutum. Lateral to this plate at each side is a smaller one with a single bristle. Ventral to this is the alar area, which has a fairly large plate, carrying posteriorly a long, and anteriorly a short bristle. The latter may belong to the scutal series, its supporting plate having fused with that on the alar region. Immediately ventral to the alar plate is the small, triangular, spiracular plate devoid of bristles; and further in the ventral direction is the epipleural plate, which occurs on the epipleural lobe—usually prominent, especially in young specimens. The epipleural plate is armed with three bristles: a long one posteriorly, and in the transverse row with posterior alar and scutellar bristles; a shorter one ventro-anteriorly; and a minute one dorso-anteriorly just below the spiracle. Ventral to the epipleural lobe are the coxal or hypopleural bristles—a long one posteriorly, and a short one anteriorly. The sternum is divided into two areas by a transverse fold. The anterior part is the presternum, and is not provided with any bristles or plates. The posterior area is the larger, and consists of the sternellum and post-sternellum. A large plate with two bristles occurs medianly on the sternellar area; and two smaller plates, which in older specimens are sometimes fused, are present on the post-sternellum. Each of the post-sternellar plates has a minute bristle medianly, and a much longer one laterally. On the post-sternellar plates of the eighth segment both pairs of bristles are minute.

The ninth abdominal segment forms the posterior extremity of the body. Dorsally it appears somewhat pear-shaped; and the tergum shows a granulated structure under a high power. It is armed with many bristles; but definite plates are not distinguishable, except a large transverse one on the sternum, which supports four long strong bristles. The other plates have fused to form the chitinised tergum. Prescutal and scutal regions are indicated by a pair of long and a pair of short bristles dorsally. Alar and epipleural regions are represented by a lateral slightly raised area, which carries one long and two short bristles. Spiracles are absent. The posterior margin is armed with a further series of three pairs of bristles; and towards the median line, at the posterior extremity, are two small circular pits. Hooks are absent. The tenth segment forms the anal proleg, and is placed

entirely ventral to the ninth. Small and narrow, it projects ventrally and slightly posteriorly to assist in locomotion, for which it is capable of being protruded and retracted. The armature consists of a transverse series of eight minute bristles near the apical border, two being posterior and the others anterior. The anus opens on the apex as a hollow slit. Unless in the region of the bristle-bearing and other chitinised plates, the cuticle of the body throughout is soft, with the surface raised into numerous, rounded, evenly distributed, wart-like tubercles (Pl. XVII, fig. 22). These are most apparent at the junction of two segments, i.e., in the intersegmental areas.

(vi) *The Spiracles.*—There are eight pairs of abdominal spiracles, all similar in structure, and placed latero-ventrally to the alar lobes. The circular peritrene is chitinised and slightly larger on the thorax and eighth abdominal segments. Surface examination shows each spiracle as a round hole, surrounded by a yellow band of chitin. This hole leads into a cup-shaped vestibule, having a small opening at the bottom. This is succeeded by a short narrow tube, having unstrengthened walls, and provided at the base with a long and a shorter arm, which project therefrom. Below these arms is a constricted area, from which the trachea proper arises. This peculiar arrangement in the spiracle was observed by Sanderson (56), but not understood. Diebel (17) and Böving (6) have since worked out the anatomy and mechanism of similarly constructed spiracles in other Chrysomelid larvae, and have shown that the two conspicuous arms which Sanderson considered as tracheal appendages belong to the spiracle, and, being provided with muscles, serve as regulators of the air-supply to the trachea. The writer has not yet had an opportunity of studying the internal anatomy of the spiracle in the larva of *L. parvulus*, but is satisfied that it is an essentially similar organ to that described for the other Chrysomelid larvae referred to above.

(vii) *Specific description of the bristles.*—In 1901 Sanderson (56) proposed a system whereby each bristle-carrying area received a number. Woods (64) followed Sanderson's idea, with modifications and additions in specific descriptions of species. The present writer has not adopted either, realizing that both are imperfect, and that it still remains for some worker on the larvae of many genera of Chrysomelidae to evolve a satisfactory scheme to include all possible variations. For example, both systems referred to provide only for larvae whose segments carry two transverse rows of bristles, whereas the larva of *L. parvulus* has three such rows, as already described. Moreover, a reference to a particular area or bristle by means of a number alone is both ineffective and cumbersome, and the system of MacGillivray (47), whereby bristles are referred to with respect to the particular area of the

segment from which they arise, is, in the opinion of the writer, more expressive.

MacGillivray's terminology is omitted here, and terms which have become general in descriptions of Coleopterous larvae substituted. Thus, the anterior tergal setae of MacGillivray are here prescutal; posterior tergal, scutellar, etc. If it is desired to specify individual bristles in detailed descriptions, it is suggested that a system of numbering in conjunction with the naming of groups according to the position they occupy be adopted. Thus prescutal I. would refer to the bristle on the prescutum nearest the dorso-median line; prescutal II. the bristle next lateral to No. 1, and so on. With such a system, the definite position of any individual bristle would at once be indicated.

(viii) *The "Prepupa"* (Pl. XVII, fig. 24).—Prior to pupation the fully fed larva undergoes certain changes whereby the shape materially alters. The body shrinks in strength while the diameter increases; and, although the new form is of a different shape, it is still essentially the last instar, as no moult occurs during the shortening process. The length is now from 2·5 to 2·8 mm., with an average diameter of 1·8 mm. The form is cylindrical, and the position usually occupied is with the head and thorax curved strongly ventralwards, thereby giving a characteristic shape (Pl. XVII, fig 24). By reason of the developing pupal structures underneath, the outline in the thoracic region is continually changing, and when nearing the last moult the thoracic sternites are pushed out into large protrusions for the accommodation of the developing legs, wings, elytra, etc., of the pupa. These structures can often be seen in suitably prepared specimens, and the one figured shows the small pads of the elytra as they appeared at that stage. The cuticle of the abdomen is now tough, and the outline of the segments well defined; the intersegmental spaces appear in cleared preparations as areas traversed by lines or folds, but still show the wart-like tubercles. Many of the bristle-bearing plates are not now separately distinct, but would appear to have become approximated.

(*c*) *The newly hatched Larva* (Pl. XVI, fig. 9).—This is elongate in form, 0·7 mm. long and 0·16 mm. broad (average of six specimens). Body light yellow in colour, with head and posterior end of abdomen dark-grey to black. Three pairs of legs well developed, also anal-proleg. Just after hatching the cuticle is nearly transparent, and the digestive system shows through; the tracheal system is now seen as fine silvery lines. The eight pairs of abdominal and one pair of thoracic spiracles are fully developed and functional. The head is comparatively large, and measures 0·15 mm. across the epicranial region. It carries the same number of bristles, and shows a similar arrangement of punctures as described for the head of the oldest

larva. The antennae are conspicuous, and the mouth-parts not different from those occurring in older larvae. The prothorax and pronotal shield are large, the latter not well chitinised, and with a distinct suture along the mid-dorsal line. It carries the normal number of bristles. The different plates of the mesothorax and metathorax are distinct; the two minute anterior alar bristles are not discernible; otherwise the arrangement is similar to that obtaining in old larvae. Epipleural lobes of abdomen not prominent; body cuticle, generally soft in the first eight segments of the abdomen, and bristle-plates indistinct. Normal number of bristles dorsally in prescutal, scutal, and scutellar series. The minute anterior alar bristle missing, and also the anterior-dorsal pleural bristle. Ninth abdominal segment large and well chitinised, and carries the normal number of bristles; they are larger than those on the other segments, especially the posterior ventral pair; these project conspicuously, and have their tips curved inwards.

(*d*) *Second-stage Larva* (Pl. XVI, figs. 10 and 11).—Length, 2·0 to 3·0 mm. Form very narrowly elongate, with the epipleural lobes projecting very conspicuously. Head, 0·19 mm. broad across epicranium. Segments of abdomen with well-defined prescutum, scutum, and scutellum. Arrangement of bristles as in final-stage larva. Bristle-plates distinct before the moult, and distantly separated owing to the expansion of the cuticle during growth. Ninth abdominal segment-bristles not longer than those on the other segments. Anal-proleg long.

(*e*) *The Pupa* (Pl. XIX).—Average length, 1·4 mm.; colour, creamy white; cuticle soft throughout, and easily crushed. The general form is short and stout, with the knees of the hind-legs projecting conspicuously at the sides, as is common in flea-beetle pupae generally. The head is bent underneath the thorax, by which it is obscured from dorsal view, while the posterior part of the abdomen is also bent ventralwards, and carries a pair of prominent curved and chitinised hooks. The developing mouth-parts are seen in week-old specimens. Antennae folded around the dorsal surfaces of the first and second pairs of legs quite near the knee-joints, and extend posteriorly and medianly to form graceful loops; their sheaths are provided with many prominent blunt processes, a circular series being present on the portion corresponding to each segment of the antenna. In young pupae the eyes of the developing adult are not distinct, but in older specimens they appear as large, dark-coloured areas, and a strong bristle arises from the pupal cuticle just above each. Besides these, the head is provided with another pair of strong bristles on the cranial region, which are supported on elevations of the pupal cuticle, while a further pair of smaller bristles occurs on the frons region. When viewed from the dorsal surface, the prothorax appears rounded

anteriorly at the vertex, from which there arise on rounded prominences two long bristles. Posteriorly, and towards the median line, are two smaller bristles, while posterior to these are two bristles of similar size to those on the vertex. A further pair arises near the lateral posterior angle, just in front of the mesothorax, and slightly dorsal and latero-ventrally at each side is another bristle. All these bristles are supported by pap-like elevations of the cuticle. The mesothorax is narrow, and carries four long bristles on similar prominences. Its posterior margin is modified to form a slight point at the median line, which projects posteriorly. This indicates the triangular scutellum of the adult. The pupal cuticle is continuous over the mesotergum and elytra, but underneath can be seen the sutures which mark the junction. The metatergum is much broader than the mesotergum, and has the scutellar groove distinctly shown as a longitudinal depression along the median line. At each side of this groove there are two bristles, thus making a transverse series of four. From the lateral angles of the metatergum the wings extend backwards around the sides of the body towards the median line on the ventral surface. The elytra extend similarly from the mesotergum, but the wings, being longer than the elytra, project well beyond the extremities of the latter. Just prior to emergence, the fine puncturing of the elytra is well seen through the pupal cuticle in suitably prepared specimens.

The legs are folded on the ventral surface, as shown in Pl. XIX, fig. 38. The front pairs are situate well forward, and are folded more or less transversely, while the hind ones are directed backwards to project at the sides of the posterior region of the abdomen. Each leg has near the knee a long and a short bristle dorsally, and a single short bristle ventrally. There are ten abdominal segments, nine of which are seen in dorsal view. Segments one to six are very much alike, and of about equal thickness. As the body tapers posteriorly, the sixth is much the narrowest transversely; the greatest breadth is attained by the second and third. Each of these segments has near the posterior margin of the tergites a transverse row of strong bristles or spines, which are supported on rounded prominences in the cuticle. Each row consists of four pairs—two pairs being dorsal, one pair lateral, and the fourth pair pleural and ventral to the spiracles.

The seventh abdominal tergite is large, and is produced posteriorly to form a rounded margin, which carries a transverse row of six long and two minute spines. The eighth tergite when viewed dorsally is small, and only projects slightly posterior to the seventh. It carries a similar transverse row of bristles. The ninth tergite is prolonged into two strong, inwardly curved, chitinised hooks, which resemble somewhat the forceps in the Forficulidae. These conspicuous structures serve definite purposes, which will be referred

to later. This segment carries at each side of the median line one long and three short bristles dorsally, two long bristles laterally, while two further bristles project between the anal hooks (Pl. XIX, fig. 42).

The tenth segment is very small, and is situated ventrally to the ninth, by which it is completely obscured in dorsal view.

The spiracles open in the pleural region of the metathorax and abdominal segments one to five; no spiracles can be seen on abdominal segments six to ten. A very short bristle occurs to the inner side of each spiracular opening, and similar bristles are present and occupy corresponding positions on the segments devoid of spiracles. The abdominal sternites are not armed, and as the pupa normally lies on its back in the cocoon, the projecting spines of the tergites serve to support the body, and prevent the possibility of damage from excessive moisture.

Unlike the pupae of some other Chrysomelidae, the males and females of this species do not differ in size. The chief external difference in the sexes is seen in the region of the two posterior abdominal segments. In the female these have, projecting from the ventral surface, two fleshy, finger-like structures, one at each side of the median line, and just anterior to the minute tenth segment (Pl. XIX, figs. 41 and 45). They serve to accommodate the palps of the ovipositor; and these organs can be seen during the later days of pupal life protruding into their pouch-like sheaths in suitably cleared specimens. In the male pupae no such projections exist; instead there is a single median enlargement, which presumably accommodates the aedeagus of the adult (Pl. XIX, figs. 43 and 44).

11.—Details of the Life-history.

In common with the other species of flea-beetles whose life-histories have been studied, *Longitarsus parvulus* spends the winter in hibernation in the adult state. Observations in Co. Derry go to show that the beetles issue from their winter quarters in spring, as soon as the weather becomes favourable—usually some time in April—and go in search of food prior to the commencement of reproductive activities. Early in May they migrate to fields of flax seedlings, and the females deposit their eggs in the soil from the middle of May onwards, according to the prevailing weather. Egg-laying may continue for about six weeks. In 1921 larvae were found from the 1st of June until late July, and pupae from the end of June until the middle of August. Emergence of the adults continued during the last weeks of July and throughout the first weeks of August. The maximum emergence of adults in 1920 was during the last week of August and the first days of September, but in 1921 a maximum was reached about the 25th July.

Prior to the emergence of these adults, and from the last week of June, few beetles are seen, because most of the old overwintering brood die before July, none having been found in the field after the middle of July, 1921. The newly emerged beetles feed for some time before going into hibernation, but they do not pair, nor do the females lay eggs; hence the species produces only one extended brood annually. If, however, the adults are caged throughout the winter on flax growing in a heated house, a brood will emerge early in May, as shown by an experiment conducted during the winter of 1920–21.

(*a*) *Pairing of the Adults.*—Actual pairing has not yet been observed, although a careful search was made from the 1st of May onwards. It is probable that general copulation had been effected prior to that date; and the fact that egg-laying commenced early in May would point to such having occurred. The warm weather which prevailed during late April of 1921 would, no doubt, influence early emergence from hibernation, and, simultaneously, early mating. Adults of *Chrysomela staphylea* and *Bembidium* sp. were observed in copulation as early as the first week of April. It is hoped to make earlier search for copulating adults next season, and in the winter quarters as well as on flax seedlings. As already indicated, no instance of mating such as that reported among some species of Chrysomelidae (38) has been observed in the newly emerged beetles prior to hibernation.

(*b*) *Oviposition.*—During the first week of May, 1921, several beetles were seen to be noticeably stouter in the abdominal region, and when such individuals were dissected, many light-yellow and nearly mature eggs were found in the ovarian tubes. These, then, are the gravid females, and as such can easily be distinguished from the smaller-bodied and more agile males. Eggs were first seen on the 16th May during the season of 1921 in one of the laboratory cages, and in the open field four days later. The latter had the appearance of having been deposited for some days, so that it is likely egg-laying commenced in the open about the 15th May, 1921. Observations on the life-history during the season 1920 were not commenced until July; but it is interesting to note that eggs were deposited by a caged female that season as late as the 10th July. No eggs were seen in the laboratory cages or in the open field after the 11th June, 1921, so that egg-laying may be said to have occupied about one month during season 1921, and to have extended from the first week in May to the first week in June, or roughly one month earlier than the single instance of egg-laying recorded in 1920.

Normally, the eggs are always deposited in the soil, but the actual position with reference to the flax plant does not appear to be important, as eggs have been found at different distances from the nearest plant. Eggs have

never been seen actually placed on the stem or roots in the open field, but in laboratory cages they have been found on the plant and on the roof of the cage, as well as in the soil. This only occurred where the cage was so small that the plant came in contact with the roof. The eggs are deposited in clusters of three, four, five, or more; but clusters of four appear to be most prevalent. Those in a cluster are firmly pressed side by side, and are often attached to a small lump of earth by means of a sticky substance at the ends.

A gravid female about to lay eggs descends from the feeding position on the plant by means of the stem to the soil. In this she chooses a suitable place in which to deposit a cluster of eggs, and this is usually somewhere near the plant, in fine soil, and covered with a few small lumps of soil, which serve as protection to the eggs. Therefore eggs are deposited in clusters just below the surface of the soil, and in close proximity to a flax plant. It cannot yet be definitely stated if oviposition occurs in flax-growing districts in soil other than that in which flax seedlings are growing. Beyond the fact that eggs were obtained over a period of one month, few data are as yet available regarding the length of individual oviposition periods, or the number of eggs deposited by each female. One female in captivity deposited thirty-seven eggs in fourteen days, but then escaped.

(*c*) *Period of Incubation.*—This, under the conditions which prevailed in the field laboratory, which differed little from those in the open, extended from fifteen to eighteen days. A record of the eggs deposited from the 16th May until the 10th June gave incubation periods extending as above, the mean of ten batches being 16·6 days.

(*d*) *Hatching.*—A short time before the incubation period is complete there is often seen a clear space towards one end of the egg, and at the same time the outline of the larva can be traced, the head being particularly distinct. From the nature of the rupture in the shell and its position, it is believed that the larva when ready for emergence uses the mandibles in the process of making the aperture through which it ultimately makes its exit. This becomes more apparent when egg-shells from which larvae have hatched are examined. Each has a similarly shaped aperture in a similar position, and corresponding to that occupied by the larval head before emergence (Pl. XV, fig. 8). It is supposed that a rounded area is first gnawed by the mandibles, and the rupture then completed by pressure of the thorax against that area.

(*e*) *Habits of newly hatched Larvae.*—These minute larvae are comparatively active, and are capable of crawling considerable distances. When hatched on blotting paper in the presence of flax roots, they crawled about slowly for some time, and ultimately went to a young portion of the root to

commence feeding. At this stage they are exceedingly fragile creatures, and highly susceptible to excessive moisture. The greatest difficulty was experienced in rearing them through to the second instar, and consequently few data regarding the first larval instar have yet been secured. Moreover, the feeding habit in the roots renders observation difficult. Individuals were seen to have moulted eight and nine days after hatching; but it cannot be said with certainty if this is the average length of the first stage. The larva becomes elongate as it grows older, but changes little in colour. Before the moult it is narrowly elongate, and the bristle plates are well seen in cleared specimens, while the head, and also the posterior extremity, appear as yellow chitinised areas.

(*f*) *Second Instar: Duration and Habits.*—The actual moulting process has not been observed; but from the study of the larva just before the moult, it is inferred that the old cuticle splits along the mid-dorsal line of the thorax, the rupture occurring in the sutures of the dorsal plates of the three thoracic segments, and continuing towards the anterior of the head by way of the epicranial and frontal sutures. Moulting is known to occur in the leaf-tunnelling larvae of *Phyllotreta nemorum* inside the tunnel; and it is believed that in the case of *L. parvulus* moulting usually occurs while the larva is still feeding in the tunnel of the root. The larva is now longer and a little stouter, and is thus admirably adapted for the habit which it possesses of burrowing into the younger roots and feeding on their soft parenchymatous tissues. Entrance is secured by means of a round hole not much larger than will admit the larva. From this hole the tunnel usually extends downwards into the younger and softer parts of the root. The larvae occasionally come out of the tunnels to enter the root again at some other part.

The length of the second larval stage was not determined by actual observation, but from the appearance of the bristle plates, and from measurements of the head, it is thought the instar has a somewhat similar duration to that of the first.

(*g*) *Final Instar: Duration and Habits.*—Feeding in the root continues for a week or more after the second moult, and the habits continue the same. When fully fed, the larva leaves the root and comes into the soil. There it wanders about, and ultimately prepares a crude cocoon of soil in which it becomes transformed by a process of shrinkage in length, accompanied by an increase in thickness, to what American workers term the "prepupa." It is simply the final instar modified into a particular form during the transition from active feeding larval life to the quiescent pupal condition.

The total larval life from the time of hatching until the "prepupa" is

formed lasts from twenty-three to twenty-eight days. An elongated and fully fed larva becomes transformed rapidly to the shortened quiescent condition; and usually on the second day after the cocoon has been completed the short and stout form is assumed. This condition persists for five or six days, during which the larva remains in a passive condition and exhibits little movement.

When the development of the pupal structures is complete, the larval cuticle splits open along the median line of the thorax, and along the epicranial and frontal sutures of the head, and the pupa emerges in the cocoon. The old cuticle is thrown off backwards, and is rarely seen attached to the pupa.

It is interesting to note here that the larvae of all the other species of *Longitarsus* studied, so far as the writer is aware, possess similar feeding habits by living in and feeding on the roots and stems of the adult's host plant. Thus the larvae of *L. echii* Koch. feed beneath the root-bark of *Echium vulgare* (53); *Longitarsus niger* Koch. larvae also penetrate and feed upon the roots of this plant. The larvae of *Longitarsus tabidus* F. live in the root-tissues of *Verbascum* spp. (54); while the larvae of *Longitarsus luridus* Scop. live in the stems of *Rhinanthus* sp. near the ground-level (55).

(*h*) *Duration and Characteristics of the Pupa.*—The pupa remains quiescent in the cocoon, but is capable, if disturbed, of making considerable movement by lashing the hinder region in circular motion. This movement occurs as the pupa lies on its back, and is permitted by the articulation of the abdomen with the thorax. When movement in the head region is desired, the anal forceps are pressed firmly against the wall of the cocoon, and when a hold is secured, the head is moved as desired. Thus the anal hooks serve to anchor the pupa in the cocoon, and they also aid considerably in the casting of the pupal cuticle. Pupae formed during the period extending from the 1st till the 25th July were kept in soil, and the adults emerged from the 14th July until the 8th August. The pupal stage therefore extends from ten to fifteen days, with an average duration of twelve days. The pupal cocoons are formed from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches below the surface of the soil.

Colour-changes in the Pupa.—When first formed the pupa is creamy white throughout, and shows no trace of pigment in the eyes. After three or four days pigment appears, and the eyes of the imago are seen as brown patches, while the rest of the pupa is still white. As development proceeds, the colour changes in many parts, so that just before the emergence of the adult the pupa has become dirty white, while the eyes appear as dark-brown to black areas occupying a considerable portion of the head region; the tips of the mandibles are orange-yellow; the femora pale-yellow, with a deeper

yellow region in their centres; and the anal hooks yellowish-brown at the tips. The development of pigment in the eyes offers a useful means for determining the age of individual pupae.

(*i*) *Characteristics of the newly emerged Adult.*—Colour, white or greyish white, with greyish black head, black eyes, and yellow femora. After three days it is greyish black all over; and after a further three days the normal colour has been assumed. Newly emerged beetles can therefore be easily recognized in late summer when they appear above ground. They are not, however, seen until the colour has become dark-grey or brown, as they remain in the soil for the first few days of adult life. Just after emergence they can jump tolerably well, but they walk with difficulty.

(*j*) *Duration of the Life-cycle.*—The transformations from oviposition to the emergence of the adult are thus completed in from fifty-seven to sixty-five days.

The figures in the following table are taken from records of rearing experiments :—

Eggs deposited.	Hatched.	Incubation period.	Fully fed larva in soil.	Feeding larval stage.	Pupa formed.	Length of non-feeding larval stage.	Adult emerged.	Length of pupa stage.	Total from egg to adult.
		Days		Days		Days		Days	Days
16.5.21	2.6.21	17	25.6.21	23	1.7.21	5	12.7.21	12	57
19.5.21	4.6.21	16	1.7.21	27	8.7.21	6	20.7.21	12	61
23.5.21	9.6.21	17	7.7.21	27	13.7.21	6	25.7.21	12	62
26.5.21	11.6.21	16	10.7.21	28	16.7.21	6	29.7.21	13	63

(*k*) *Hibernation of the Adults.*—As soon as the weather gets cold, feeding ceases, and winter quarters are secured. Hibernation occurs beneath the shelter of grass, weeds, moss, &c., near dry fences in the neighbourhood of the fields which supported them during the previous weeks. Hibernating beetles are also found in crevices in walls, gate-piers, woodwork, &c.; in outhouses, adjacent to flax fields, and even far out in fields from which flax has been pulled, if these are provided with old grass and weeds to afford shelter. In January, 1921, the writer made a study of the hibernating quarters, and found beetles in the different places as stated. Some go down into the soil for a short distance, while others are found in crevices and cracks in the soil, or even on the surface beneath grass, &c. When first seen they are quite inactive, with the legs gathered underneath the body, and the

antennae folded by the sides. They lie in the normal position. On the application of slight heat, or when disturbed, slow movement begins; and after the legs and antennae have assumed the normal positions, a beetle may commence to walk or even jump away from the place of hibernation. Even then, however, they are sluggish in movement and readily reassume a quiescent state.

Hibernation usually occurs in October, or in late September, if the weather is severe. In early October, 1920, the beetles were observed going into hibernation, although individuals were seen on the 19th of October feeding on flax seedlings which were growing in the dug portion of a potato field from seed spilled there.

12.—Natural Checks and Enemies.

Various birds were seen to prey on the larvae and pupae when exposed to their view. Some adults become entangled in the webs of spiders placed near the soil, and thus fall a prey to them. A carabid beetle, *Bembidium lampros* (which Mr. Halbert kindly identified), was seen early in May to attack the gravid females; and by placing three of the latter in a tube containing some small lumps of soil with two of the carabids, it was found that by next day two of the flea-beetles had been devoured.

It is highly probable that *B. lampros* is also predaceous on the eggs, although this has never been actually observed. This species of ground beetle was exceedingly abundant in the soil of the experimental plots throughout the 1921 season.

Larval mites of the family Trombidiidae have been found attached to the adults. One specimen which Mr. Halbert believes to be the larval form of *Rhyncholophus phalangeoides* was attached to the abdominal tergites underneath the right elytron. Many mites belonging to the family Tyroglyphidae have been found attacking larvae and pupae in rearing cages; but their presence was probably accidental, and they cannot be regarded as natural enemies in free life.

The larvae and pupae appear to be singularly free from the attacks of Hymenopterous parasites. Not a single internal parasite has been reared from the hundreds of larvae and pupae collected outside and brought through to the imago in the laboratory. This would appear to be the general condition in the flea-beetle group.

13.—Suggestions for Control Measures.

It is an acknowledged fact that weak, slow-growing seedlings in thin brairds are, for some unknown reason, particularly liable to attack, and,

because they are less capable of outgrowing and overcoming the attack, suffer more than those in strong, vigorous brairds. It follows, therefore, that anything which tends to encourage the strong, vigorous growth of the seedlings is, indirectly, a preventive measure against the chances of extensive damage. Hence the importance of using only seed of first-class germinating capacity, and of sowing it only on suitably prepared and properly manured fields.

As already suggested, the time of sowing may have a considerable influence on the intensity of an attack; and, as the earlier brairds often suffer considerably, while those appearing later practically escape, it is evident that very early sowing is not desirable in districts where the flax flea-beetle is prevalent. It is certainly not desirable to sow isolated fields early, but rather should it be the aim to get all the flax in a particular district sown at approximately the same time, as the beetles, when spread over a considerable area, are less liable to cause serious damage in any particular field.

The sowing of small areas of flax at least one week earlier than the main part of the crop, and using these areas as traps on which to catch beetles attracted thereto, suggests itself as a method whereby large numbers may be destroyed. The destruction of the beetles is best achieved by sweeping over the seedlings a sack or light board, coated with tanglefoot or other sticky material, in which the disturbed beetles are caught and held. Such operations give best results when done during bright sunlight (when the beetles jump most readily from the food plants), and in such a manner as to facilitate their jumping against the sticky board when disturbed. The sweeper should be regularly cleaned, and fresh coats of the sticky material applied. As the beetles appear to be attracted to white-coloured areas, the sweeper should be as white as possible, and, even when left lying in the vicinity where beetles abound, these sweeping boards may trap considerable numbers.

Further destruction may be effected by the thorough cultivation of the trap plots in late June, which kills any eggs laid during May and early June, and any larvae newly hatched therefrom.

Excellent results have been obtained from the use on attacked seedlings of light dressings of stimulating manures before the attack has extensively developed. Thus, a dressing of not more than ½ cwt. of nitrate of soda per statute acre has been found highly beneficial when applied to attacked brairds.

Trials of various possible remedies were made at Coleraine during the season 1921. These consisted of dressings of the seed, and dusts and sprays applied to the seedlings. Some of the latter were intended to act as repellents by creating a noxious smell, or otherwise making the seedlings distasteful to the beetles; others were intended to act as poisons; while a few were

expected to have both these properties. Most of the experiments gave indefinite information owing to the unusually slight infestation. There were, however, indications that a few possessed effective properties; but many further tests are necessary before they, or modifications thereof, can be recommended. The very evident uselessness of other treatments tested pointed to the conclusion that further trials with such would be superfluous.

With the object of determining the effect, if any, of various seed dressings, some of which were reputed to impart protective properties, small plots were sown with seed previously treated as follows :—

1. No dressing (control).
2. "Nilfli" powder, mixed dry with the seed.
3. Powdered naphthalene, mixed dry with the seed.
4. Two per cent. copper sulphate solution.
5. Two per cent. copper sulphate solution, plus paraffin oil.
6. Paraffin alone.

The powders were mixed at the rate of 21 lbs. to 7 pecks of seed, while the liquids were sprayed on during continual stirring, and until the seed became thoroughly wetted. Slaked lime was used as a drying agent, and sowing done directly afterwards. The germination was not adversely affected by any of the treatments employed, but in no case was the slightest protection afforded to the seedlings. All six plots were equally badly attacked, and no difference could be seen in the severity of the attack on the control plot when compared with each of the others.

The following substances were applied in powder form to the seedlings, and as far as possible in the presence of dew, to ensure better adhesion to the foliage :—

1. Flowers of sulphur, 1 cwt. per acre.
2. Corry's tobacco powder, 1 cwt. per acre.
3. Pyrethrum powder, 1 cwt. per acre.
4. Soot, 6 cwt. per acre.
5. Soot and lime, equal parts, 6 cwt. per acre.
6. Road dust, 6 cwt. per acre.

Negative results were obtained from each of these powders, no obvious protection being afforded the seedlings in any of the plots so treated.

The glabrous nature of flax foliage is responsible for a serious difficulty with regard to sprays for the seedlings. Moreover, the habit possessed by the beetles of feeding only on the newly opened foliage renders the effective

destruction of the insects with a poison wash sprayed on the seedlings more remote, since new foliage untouched by the poison wash is rapidly produced. Therefore, when considering likely useful washes, the possibility of improving the adhesive properties of well-known poisonous substances by the addition of agents reputed to impart such properties was primarily considered, as was also the possibility of combining a wash which, as well as being poisonous, had a deterrent effect. Different strengths of Bordeaux mixture were used alone, and also with the addition of (*a*) casein, (*b*) flour paste, and (*c*) soft soap, to test the comparative adhesive and spreading properties of the resulting mixtures. These properties were not, however, observed to be appreciably increased by any of these substances. Bordeaux mixtures, with the addition of (*a*) lead arsenate, (*b*) 98 per cent. nicotine, (*c*) lead arsenate and flour paste, and (*d*) lead arsenate and soft soap, were also tried. The last-named mixture scorched the seedlings, but not beyond recovery. In all the other cases no appreciable damage to the seedlings could be detected. Other washes used were lead arsenate, lead arsenate-paraffin emulsion, potassium chromate, potassium sulphide, Burgundy mixture, and copper sulphate solution alone.

Lead arsenate spreads and adheres very indifferently to flax seedlings, while lead arsenate-paraffin emulsion would appear to be little better; moreover, the latter scorched and browned the seedlings to a considerable extent. Both potassium sulphide and chromate are poor spreaders, and adhere badly, so that they are unsuitable for use alone on flax. The former was intended to neutralize the supposedly attractive stimulus emitted by the brairding seedlings, but it did not appear to possess that property.

The slight infestation of beetles during the season is to be regretted from the point of view of testing possible remedies, and little can be said regarding the usefulness or otherwise of many of the washes used. Bordeaux mixture, however, gave indications of acting as a deterrent to the influx of beetles on plots to which it was applied alone, or in conjunction with lead arsenate or nicotine.

A Bordeaux mixture containing about 1½ per cent. of free copper sulphate was also tested, and this, besides having the deterrent properties of the others, had the effect of destroying weeds such as Spurrey (*Spergula arvensis*) and Charlock (*Sinapis arvensis*), both of which were present to a considerable extent; the flax seedlings were not, however, injured. Next season it is hoped to continue experiments dealing with probable preventive and remedial measures.

Finally, it should always be borne in mind that to wage war on anything about the farm that is calculated to afford shelter for the beetles during the

winter is, indirectly, a preventive measure against future attacks. Hence all grass and weeds present on fields from which a crop of flax has recently been removed (besides that occurring on ditch-backs and dry banks beside or near such fields) should be destroyed or grazed bare by stock, for by so doing the beetles are deprived of many suitable places for hibernation, and are, consequently, exposed to greater risks during the winter months.

It is the writer's opinion that the practice of sowing grass seeds with the flax, common in some districts, facilitates the perpetuation of this pest, because such a practice provides for the needs of the beetles at critical periods. Thus, after the flax has been pulled and removed, they have ample suitable food in the young grasses and clovers, and, later, sufficient protection for hibernation is afforded practically anywhere in the field.

Thorough cultivation after the removal of the flax, besides removing food and hibernation quarters, is desirable from another aspect. If, as was the case in 1920, the brood of beetles has not emerged at the time of pulling the flax, many of the soft, delicate pupae in the soil will be destroyed or brought to the view of birds by such processes. These cleaning and cultivating operations are purely preventive measures; but now that more is known of the life of the pest, they at once suggest possibilities in the keeping down of numbers, and thus minimizing future attacks.

14.—Summary.

1. This paper deals with the flax flea-beetle (*Longitarsus parvulus* Payk.), a serious insect enemy of flax, and one responsible for considerable loss to growers of this crop in Ireland.

2. The history and synonymy, identity, distribution, and allied species are discussed. In Ireland the species is commonly found all over Ulster, and of recent years it has become a pest in flax-growing districts in Co. Cork.

3. The adult is a leaf-eater, and causes serious damage to brairds of flax seedlings. By eating the cotyledons and growing point many of the seedlings are killed outright, while others remain small and stunted, and many become branched.

4. Cultivated flax is the favoured food-plant of the adults, but they also eat clovers, grasses, and species of wild flax.

5. Past records of damage to flax are given, with a discussion on the conditions which probably favour attacks.

6. The life-history has been followed, and the immature stages are described and figured for the first time.

7. The adults hibernate in sheltered positions underneath grass, weeds, etc., and in cracks and crevices in the soil or in ditches and walls, during the winter, and come out in spring, when the weather becomes favourable.

8. The females lay eggs in the soil in which flax is growing from early May to late June. These hatch in sixteen days, giving rise to minute larvae, which bore into and feed on the roots of the flax plants, but do not appear to cause any appreciable hindrance to growth.

9. The feeding larval life occupies about twenty-seven days, during which time the larvae increase in size and become slenderly elongated in shape. When fully fed the larvae leave the root-tunnels and go into the soil, where they transform to pupae in crude cocoons of earth.

10. The pupa is small and stout, soft and white, and from it the adult emerges after twelve days. Emergence reached a maximum in Co. Derry about the 25th July, 1921, which was a month earlier than that observed the previous season.

11. The complete life cycle from egg to adult is passed in about sixty days, and there is only one generation annually.

12. The species is particularly free from the attacks of internal parasites, and no serious natural enemy has been observed.

13. Preventive measures consist of the production of strong, vigorous growing brairds by the employment of suitable cultivation, seed, and manure ; and in the destruction or removal of all likely hibernation quarters, especially near fields which recently grew a flax crop. Early sowing of isolated fields should be avoided.

14. The stimulation of attacked seedlings by the application of a light dressing of nitrate of soda has proved beneficial.

15. Experiments carried out in Co. Derry during the 1921 season indicate the possibility of the use of Bordeaux mixture as a deterrent. Owing, however, to the very slight infestation that season, the information gained from trials on possible remedial sprays is not sufficient to warrant the recommendation of any particular treatment, and further trials are very necessary and desirable in this connexion.

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EXPLANATION OF PLATES.

PLATE XV.

Fig.

1. Photograph of flax seedlings, showing early effect of flea-beetle attack. (Natural size.)
2. Cotyledons of a seedling enlarged to show the holes and notches made by the beetles. (× 3.)
3. An enlarged photograph of a seedling, showing the central bud eaten. (× 3.)
4. Photograph of older seedlings, showing the general effect of an attack. (Natural size.)
5. Enlarged photograph of an older seedling after a severe attack. (× 3.)

PLATE XVI.

6. Eggs of *Longitarsus parvulus*. (× 75.) *ps*, pad of sticky substance often present at the end.
7. Portion of the egg-surface very highly magnified.
8. Egg after hatching. (× 85.) *ea*, emergence aperture of larva.
9. Newly hatched larva. (× 122.)
10. Second stage larva; dorsal view. (× 50.) *prs*, prescutum; *sc*, scutum; *scut*, scutellum.
11. Second stage larva; lateral view, with cuticle cleared. (× 50.)
12. Dorsal view of thorax of mature larva, showing the arrangement of the bristle-bearing plates. (× 70.) *su*, pronotal suture; *P*, prothorax; *Ms*, mesothorax; *Mt*, metathorax.
13. Ventral view of thorax and first abdominal segment of mature larva, showing the sternal plates. Legs removed. (× 70.) *P*, prothorax; *Ms*, mesothorax; *Mt*, metathorax; *A1*, first abdominal segment.
14. Plan of bristles and bristle-carrying plates of abdominal segments one to eight. Drawn from third abdominal segment. (× 70.) *MD*, mid-dorsal line; *MV*, mid-ventral line; *prs*, prescutal plates and bristles; *sc*, scutal plates and bristles; *scut*, scutellar plates and bristles; *al*, alar plate and bristles; *sp*, spiracular plate and spiracle; *ep*, epipleural plate and bristles; *hyp*, hypopleural plate and bristles; *st*, sternal plates and bristles.

Plate XVII.

Fig.

15. Dorsal view of posterior extremity of fully grown larva. (× 105.) *A8*, eighth abdominal segment; *A9*, ninth abdominal segment; *epl*, epipleural lobe and bristles; *scub*, scutellar bristles.
16. Lateral view of posterior extremity of fully grown larva. (× 105.) *A8*, *9*, *10*, abdominal segments 8, 9, and 10; *sp*, spiracle; *epl*, epipleural lobe.
17. Ventral view of posterior extremity of fully grown larva. (× 105.) *an*, anus; other lettering and figures as before.
18. Left mesothoracic leg of larva; inside view. (× 550.) *tu*, tunica; *cl*, claw; *ts*, tarsus; *tb*, tibia; *cx*, coxa; *fm*, femur; *tr*, trochanter; *ac*, acetabulum.
19. Right metathoracic leg of larva; outside view. (× 550.) Lettering as above.
20. Seventh abdominal spiracular plate and spiracle; surface view. (× 1,100.)
21. Seventh abdominal spiracle; lateral view. (× 1,100). *nk*, neck of spiracle; *aca*, arms of the closing apparatus; *tra*, trachea.
22. Portion of the larval cuticle very highly magnified.
23. Final-stage larva drawn from life. (× 38.)
24. "Prepupa" of final instar from life. (× 47.) *1–10*, abdominal segments; *wp*, outline of developing wing-pads of pupa; *al*, alar lobe of metathorax; *epl*, epipleural lobe of fifth abdominal segment; *prs*, prescutum; *sc*, scutum; *scut*, scutellum; *sp*, spiracle.

Plate XVIII.

25. Head of fully grown larva; ventral view. (× 200.) *an*, antenna; *ca*, cardo; *cl*, clypeus; *ep*, epipharynx; *epc*, epicranium; *gal*, galea; *gu*, gula; *hyp*, hypopharynx; *lbr*, labrum; *lig*, ligula; *lp*, labial palp; *me*, mentum; *mn*, mandible; *mp*, maxillary palp; *pfl*, labial palpifer; *pfm*, maxillary palpifer; *pr*, prothorax; *sm*, submentum; *st*, stipes.
26. Head of larva; dorsal view. (× 200.) *eps*, epistome; *epsu*, epicranial suture: *fr*, frons; *frr*, frontal ridge; *frs*, frontal suture; *upb*, ultraposterior punctures and bristles. Other lettering as in fig. 25.
27. Head of larva; lateral view. (× 200.) *pls*, pleurostome. Other lettering as in fig. 25.

Fig.

28. Right antenna of larva; dorsal view. (× 600.) *1*, *2*, *3*, segments; *spr*, sensory projections.
29. Right mandible; inside view. (× 600.) *abd*, abductor muscle; *add*, adductor muscle; *cd*, condyle.
30. Left mandible; inside view. (× 600.) Similar lettering.
31. Right maxilla; ventral view. (× 600.) *ca*, cardo; *gal*, galea; *lac*, lacinia; *mp*, maxillary palp; *pfm*, maxillary palpifer; *st*, stipes.
32. Hypopharynx and maxillae; inside view. (× 375.)
33. Left maxilla; inside view. (× 600.) *gal*, galea; *hyp*, hypopharynx; *lac*, lacinia; *mp*, maxillary palp; *pfm*, maxillary palpifer.
34. Labrum and clypeus; dorsal view. (× 520.) *cl*, clypeus; *pb*, punctures with minute bristles.
35. Clypeal punctures and bristles. (Very highly magnified.)
36. Epipharynx. (× 520.)
37. Labium; ventral view. (× 600.) *hyp*, tip of hypopharynx; *lig*, ligula; *lp*, labial palp; *pfl*, labial palpifer; *me*, mentum; *sm*, submentum.

PLATE XIX.

38. Female pupa; ventral view. (× 65.)
39. „ „ ; dorsal „ (× 65.)
40. „ „ ; lateral „ (× 65.)
41. Anal segments of female pupa; ventral view. (× 125.)
42. „ „ male „ ; dorsal „ (× 125.)
43. „ „ male „ ; lateral „ (× 125.
44. „ „ male „ ; ventral „ (× 125.
45. „ „ female „ ; lateral „ (× 125.)

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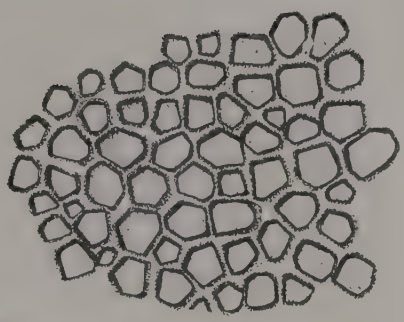

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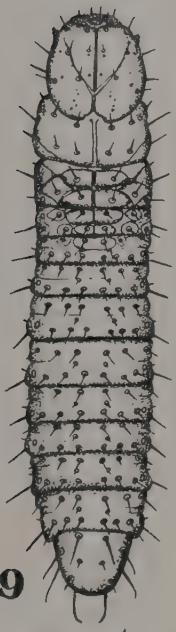

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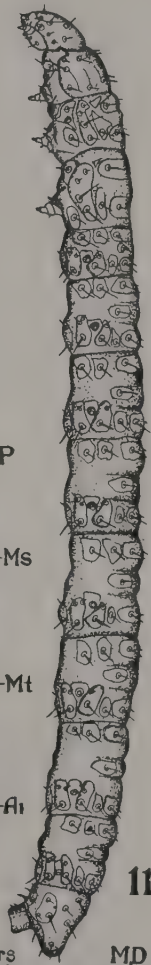

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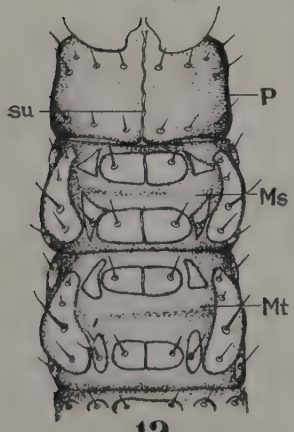

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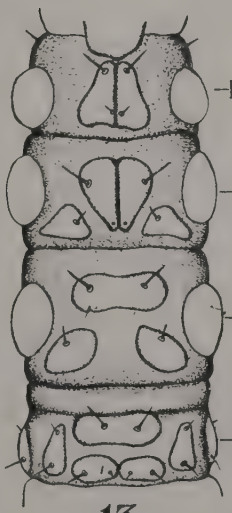

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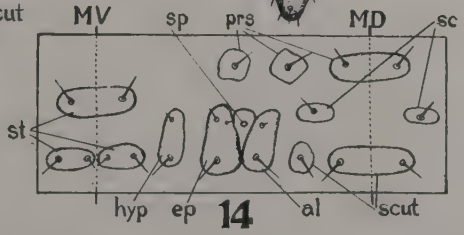

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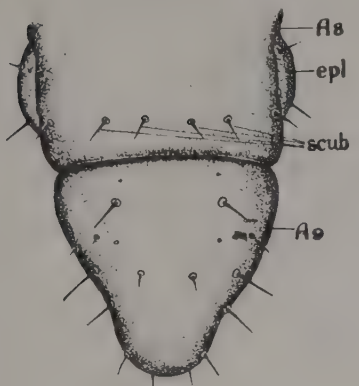

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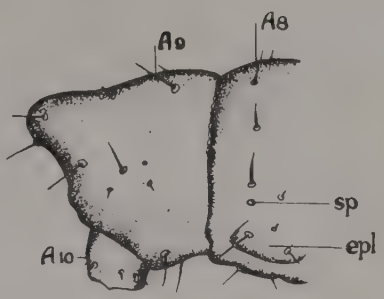

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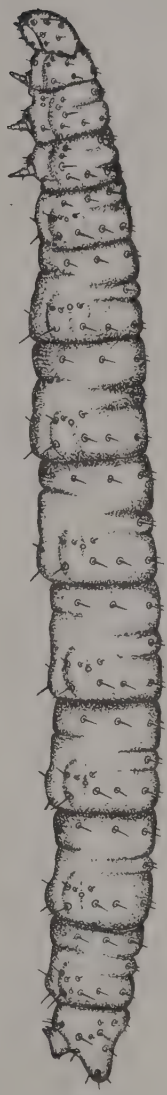

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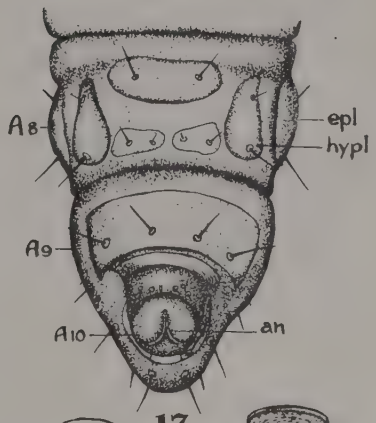

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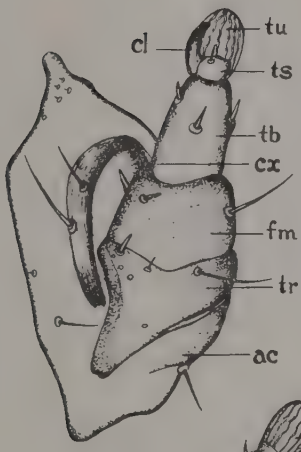

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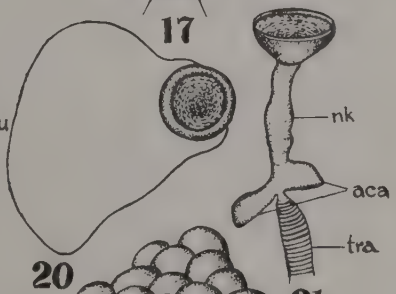

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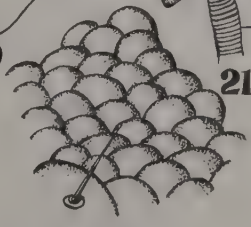

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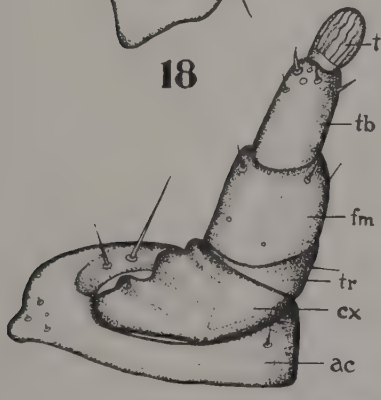

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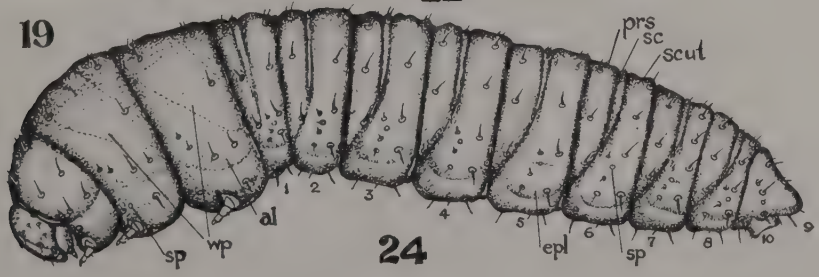

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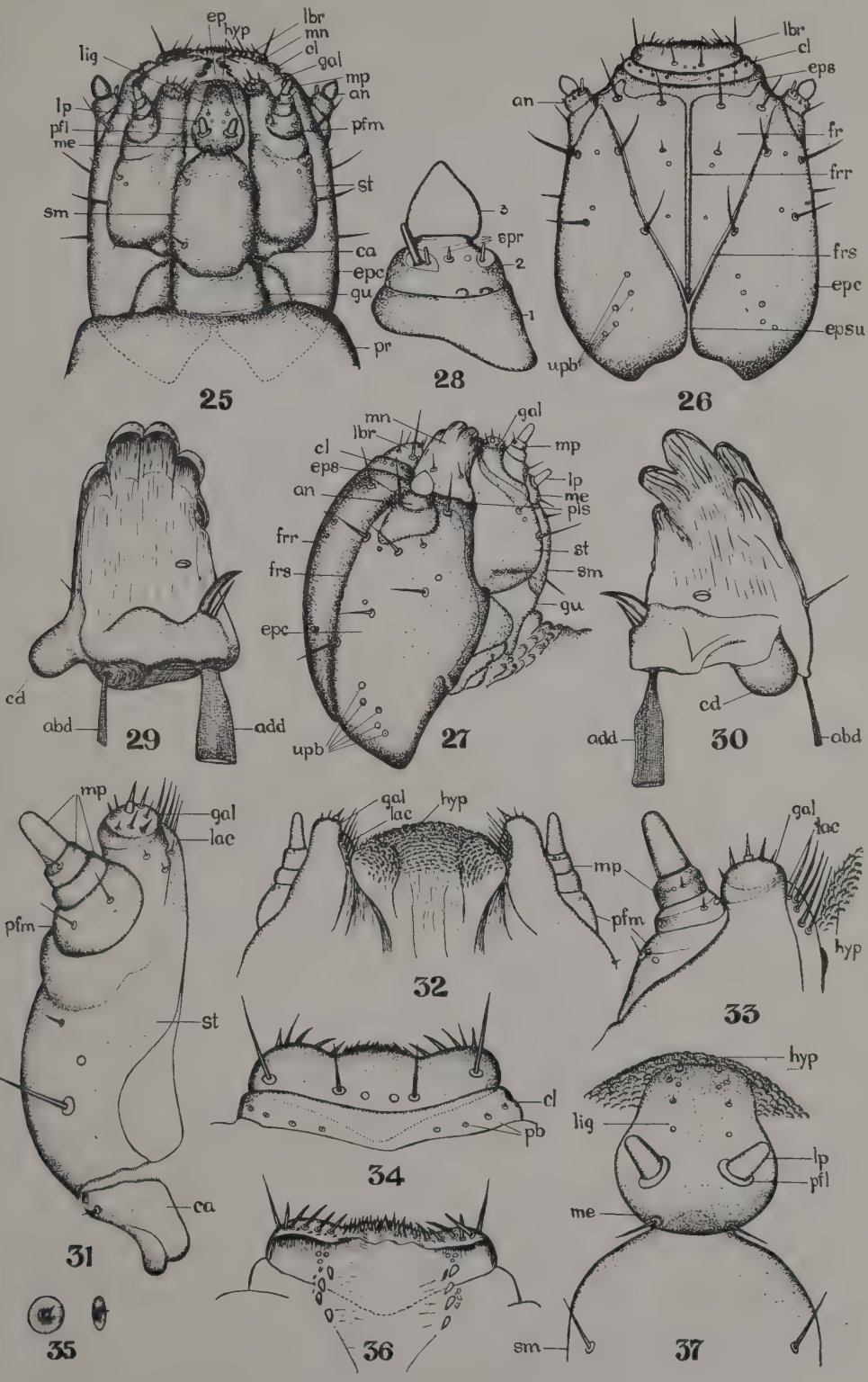

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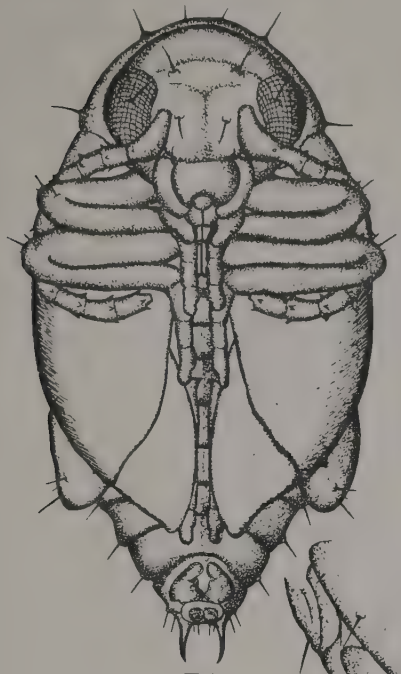

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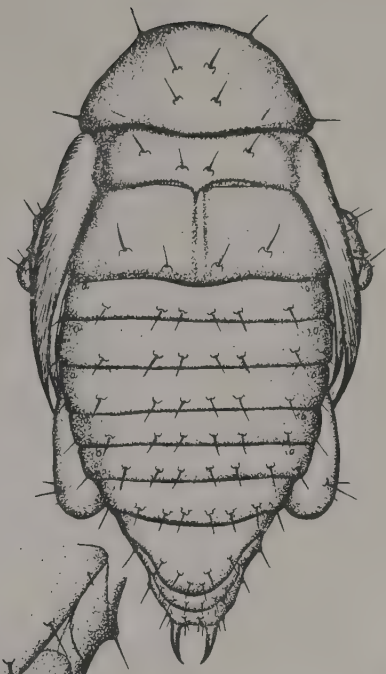

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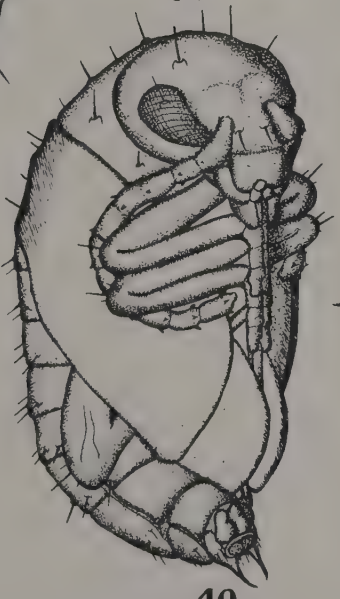

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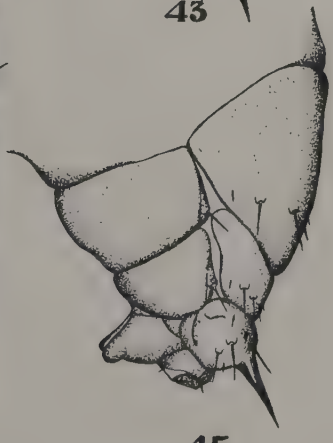

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